EFFECTS OF AN ACOUSTIC WAVE IN THE POSITIVE COLUMN OF A GLOW DISCHARGE

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THESIS

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Effects of an Acoustic Wave in the

Positive Column of a Glow Discharge

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ABSTRACT

An alternating current produced by an acoustic wave in the positive column region of a glow discharge in nitrogen gas under dc conditions was measured using a magnetic probe in the form of a Rogowsky Ring. The electrodynamic speaker which generated the acoustic wave was calibrated in nitrogen gas in terms of acoustic pressure for frequencies from 50 Hz to 250 Hz at ambient pressures corresponding to glow discharge pressures through the use of a specially constructed mobility-limited thermionic diode. The frequency of the perturbation current was found to be the same as the frequency of the acoustic wave and its magnitude was a function of ambient pressure, dc discharge current, acoustic pressure, and acoustic frequency.

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ACKNOWLEDGEMENTS

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I. INTRODUCTION AND SCOPE OF THE EXPERIMENT

Investigation of acoustic waves in a weakly ionized gas has been of primary interest to many authors during the past decade. At the Naval Postgraduate School much work has been done concerning the acoustical effects of moving striations in a glow discharge [1, 2, 3, 4 and 5]. In 1966 Ingard [6] presented a theoretical approach to acoustic wave generation and amplification in a plasma. Ingard and Schulz [7] later revised and expanded this previous work to include a discussion of the causes of charge separation brought about by an acoustic wave in a weakly ionized gas. In this analysis they considered a weakly ionized gas as a three fluid model composed of neutrals, ions, and electrons and defined an acoustic wave mode as a perturbed version of an ordinary sound wave in a neutral gas. In their analysis, Ingard and Schulz showed that in the presence of an acoustic wave, the neutrals, electrons, and ions had the same displacement amplitude and were in phase with the wave only at comparatively low frequencies. When the acoustic frequency exceeded a characteristic value given by

$$\omega_c = \Omega_n \left(\frac{T_n N_n}{T_e N_i}\right) \gamma_n$$

where the subscripts n, i, and e stand for neutrals, ions, and electrons, and Ω_n is the collision frequency of neutrals with charged particles, the ion and electron velocities decreased in amplitude and were brought

out of phase with the motion of the neutrals. In addition the ion and electron velocities in the presence of an acoustic wave were slightly different. It is possible that as the acoustic wave passed any given point within the discharge, ionization increased to a maximum value when the acoustic pressure was a maximum at that point. The electrons and ions then diffused away, but the electrons, because of their smaller mass, diffused more rapidly creating a space charge condition and charge separation. This charge separation produced an electric field perturbation that traveled along with the acoustic wave.

Prior to the theoretical approach by Ingard and Schulz, experimental observations of low frequency acoustic standing and traveling waves in a weakly ionized gas by Subertova [8] revealed the modulation of ion and electron densities which led to charge separation and the appearance of an alternating electric field. This alternating electric field superimposed on a dc glow discharge had associated with it an alternating perturbation current which was a function of discharge and acoustic parameters.

The scope of this experiment was to further investigate the perturbation current created by a low frequency acoustic wave in the positive column of a nitrogen gas glow discharge. The planned procedure was to measure the perturbation current as a function of acoustic frequency, acoustic pressure, discharge dc current, and discharge pressure through the use of a toroid with a high permeability core (Rogowsky Ring) as a diagnostic device. This Rogowsky Ring had to be constructed

and, based on the previous experimental work by Subertova, it had to be sufficiently sensitive to measure a perturbation current on the order of several microamperes. This project was essentially the same as that carried out by Subertova except that this experiment included calibration of the acoustic transmitter in terms of acoustic pressure in order that a determination of perturbation current as a function of acoustic pressure could be made.

II. EXPERIMENTAL EQUIPMENT

A. DISCHARGE TUBE AND SPEAKER ASSEMBLY

A standard electrodynamic speaker was used to create the acoustic wave. Subertova, in her work, experimented with other less powerful devices and/or methods such as current modulation of the discharge and found that they did not create sufficient acoustic pressure to cause a measurable perturbation current. In addition an electrodynamic speaker was desirable since it produced an acoustic wave with a narrow bandwidth for any selected frequency.

It was necessary to install the speaker within the vacuum system. However, while under vacuum, the chemicals impregnated in the speaker cone outgassed. This outgassing caused a two-fold problem: 1) the outgassing limited the ultimate vacuum obtainable in the discharge tube to approximately 1×10^{-6} torr and 2) the chemicals which outgassed introduced impurities in the discharge. It was therefore planned to separate the speaker housing from the discharge tube with some type of diaphragm which would still pass the acoustic signal.

The discharge tube was fabricated from 2 inch inside diameter pyrex conical pipe 2 feet in length and fitted at each end with industrial joints. The 2 foot length was compatible with the power supply used to create and maintain the glow discharge at desired tube pressures. The top cap consisted of a machined aluminum disk bolted to the discharge tube with an aluminum flange and molded insert. An efficient seal was

obtained by inserting an "O"-ring between the top cap and discharge tube. The top cap was also fitted with Swagelock tube fittings which permitted 8mm glass tubing to be inserted into the discharge tube to any desired depth and then sufficiently sealed to maintain a vacuum by simply hand tightening the knurled knob. Each electrode consisted of a 0.5 inch diameter tantalum cylinder 1 inch in length. A cylindrical shape was chosen to minimize the influence of the electrodes on the acoustic wave. The kovar lead to the anode was sealed in 8mm glass tubing and inserted into the discharge tube through the Swagelock fitting. The cathode was permanently mounted 3 inches above the bottom of the discharge tube with the kovar lead penetrating the wall of the tube in a glass to metal seal. The bottom of the discharge tube was bolted in a similar manner as the top cap to another machined aluminum disk with a 2 inch hole in the center. The bottom disk consisted of an upper and lower half with each adjoining surface containing an "O"-ring. A piece of 0.5 mil Mylar sheet was placed between the upper and lower halves to form a diaphragm which separated the discharge tube from the speaker housing. The discharge tube was connected to the vacuum system through a greased ball-joint connection directly opposite the cathode seal.

A 5 inch diameter 10 watt electrodynamic speaker was housed in a 6 inch to 2 inch inside diameter pyrex conical pipe reducer. The discharge tube and diaphragm assembly was bolted to the top of the speaker housing with an aluminum flange and molded insert. The bottom of the speaker housing was bolted to a machined aluminum base plate in a

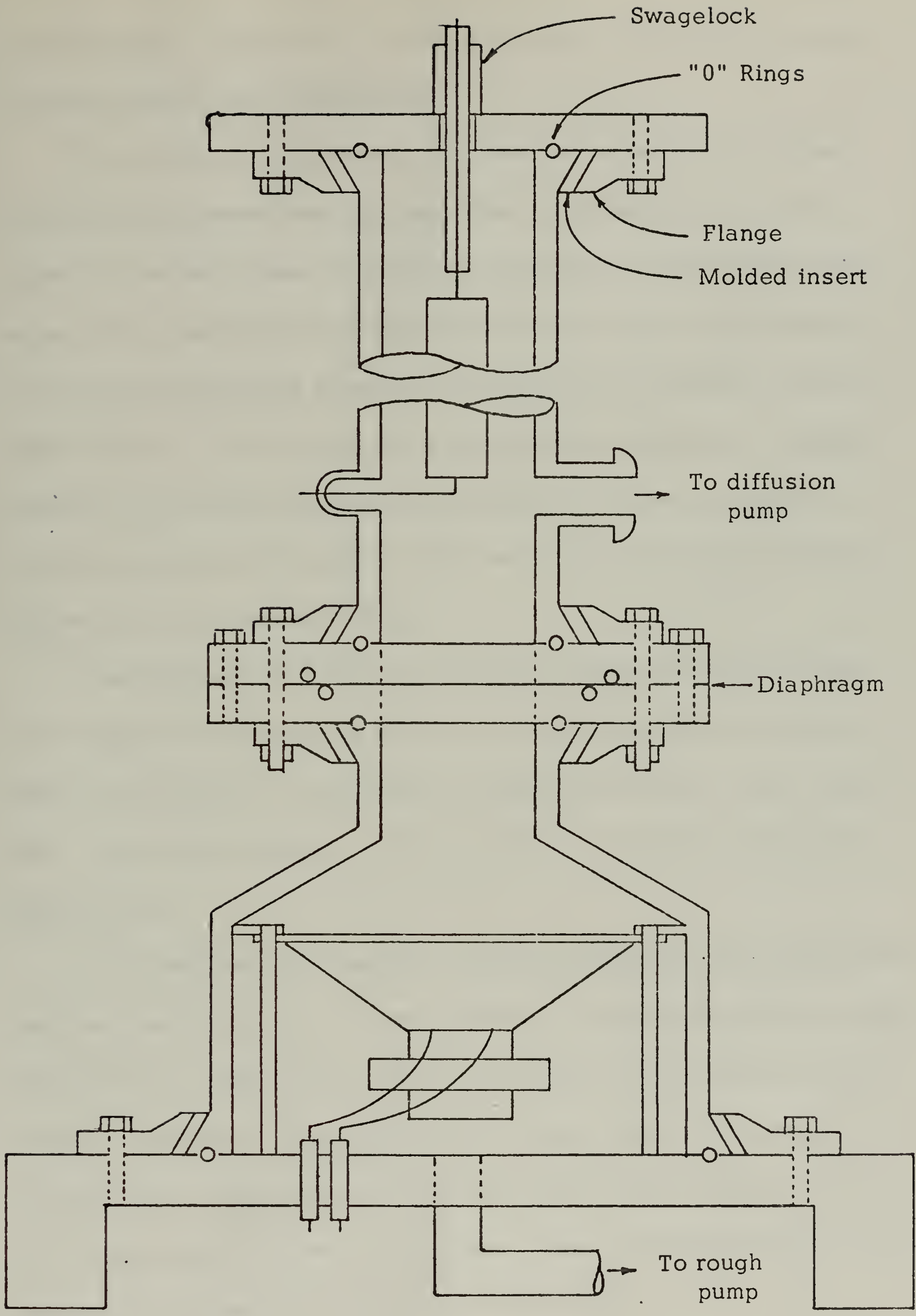

Figure 1. Discharge tube and speaker assembly

similar manner. Again an "0"-ring was placed between the housing and base plate to form a tight seal.

The speaker was supported 31 inches below the top cap by four legs extending upward from the base plate. An aluminum collar was placed around the speaker in such a manner that the collar touched the inside of the speaker housing thus acting as a baffle. The aluminum base plate contained the speaker feedthroughs and a vacuum line to a Cenco HYVAC 7 vacuum pump which allowed evacuation of the speaker housing to approximately 10 microns pressure. It was necessary to evacuate the speaker housing in order not to have too great a pressure differential across the diaphragm.

The Rogowsky Ring which was placed around the discharge tube was supported in place by an aluminum platform through which the discharge tube passed. The platform slid along four vertical rods, one at each corner of the platform, and was held at any desired position by a screw clamp.

This design of the discharge tube and speaker housing proved to be extremely advantageous as it was possible to replace the speaker and/or insert probes, diodes, etc., into the discharge tube easily and within minutes. Although "0"-rings have the inherent property of acting as "virtual leaks," they proved to form tight seals and a vacuum of 3.0×10^{-7} was achieved in the discharge tube when a diaphragm was in place between the discharge tube and speaker housing.

B. DISCHARGE CIRCUIT

The dc glow discharge was established using the circuit shown in Fig. 2. A Sorenson model 1006-100 dc high voltage regulated power supply and model 1006-100 HV filter together with a 10K ohm 55 watt resistor allowed operation of a glow discharge in nitrogen gas at pressures in excess of 5 torr with a discharge current up to 70 mA. The Sorenson power supply provided 0 - 6000 volts and 100 mA current with less than .01% ripple. The bottom electrode was maintained at ground potential and always acted as the cathode. This arrangement prevented breakdown from occurring from this electrode to the speaker. The top cap was not insulated and was therefore allowed to assume the same potential as the plasma within proximity. Discharge current was measured with a Keithley 600B electrometer.

C. SPEAKER CIRCUIT

The speaker circuit was as shown in Fig. 3. The frequency signal was obtained from the local oscillator in a PAR model HR-8 lock-in amplifier operated in the internal mode. A Hewlett Packard 521-AR electronic counter was used to adjust the frequency of the PAR accurately. A Bogen CHB 10-A amplifier was used to drive the 10 watt, 8 ohm speaker, and a Ballantine 311 VTVM was used to measure accurately the signal strength to the speaker. The input signal strength to the speaker was important in regulating the acoustic pressure.

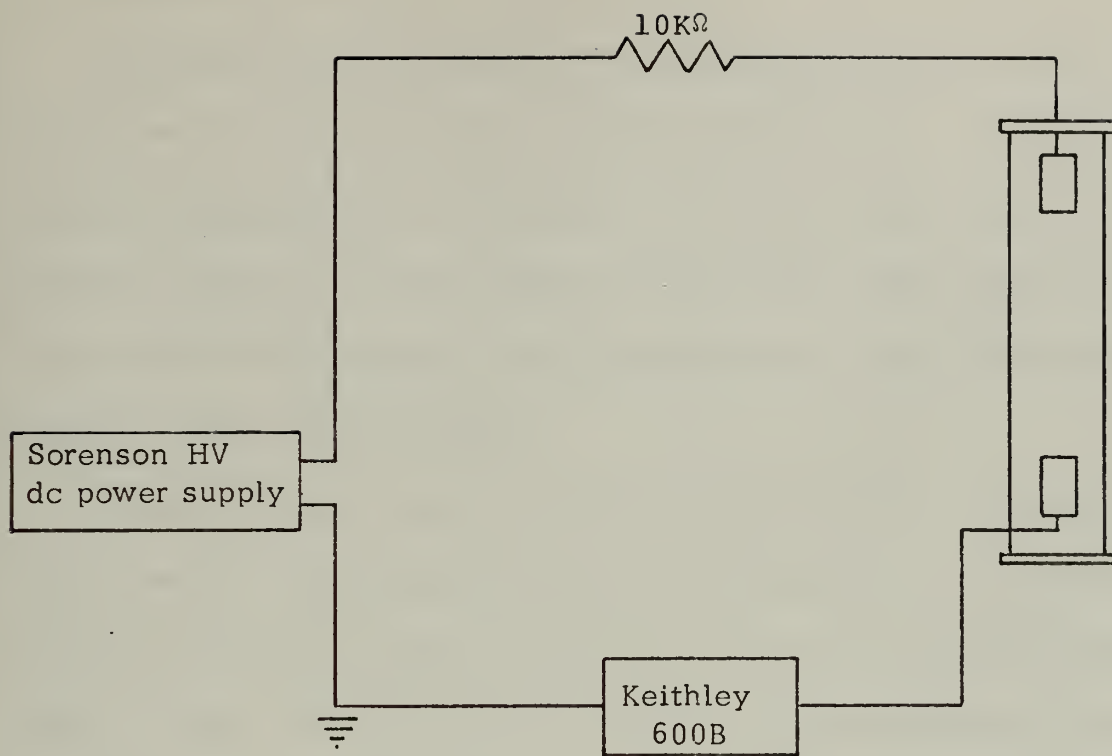

Figure 2. Main discharge circuit

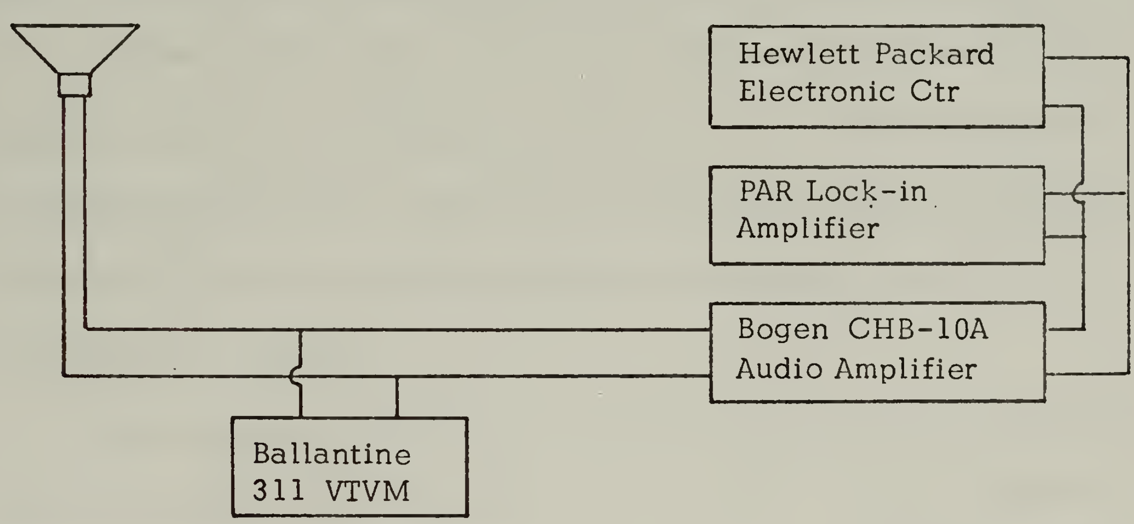

Figure 3. Speaker circuit

D. VACUUM SYSTEM

The Cenco HYVAC 7 vacuum pump used to evacuate the speaker housing was also used to rough pump the discharge tube. Once rough pumping to approximately 10 microns was completed, high vacuum in the discharge tube was achieved using a Cenco HYVAC 14 fore pump and a Veeco model 2A1 oil diffusion pump equipped with a liquid nitrogen cold trap and an air-cooled condenser.

Pressures in the vacuum system were measured with a thermocouple in the fore line of the diffusion pump, with a thermocouple located in the roughing out line, and with an ion gage on the low pressure side of the diffusion pump. These devices were used in conjunction with a Veeco type RG-3A vacuum gage controller.

Ambient nitrogen gas pressure in the discharge tube was determined with an oil filled manometer located on the gas fill manifold.

Pressures of the order of 10^{-8} torr were readily achieved in the system up to but not including the discharge tube. Higher pressures in the discharge tube were a result of not being able to bake the discharge tube properly because of the greased joint connections and because of the numerous "0"-rings.

The Cenco rotary pumps were extremely noisy and steps had to be taken to minimize vibration of the vacuum system. Also, the HYVAC 14 fore pump was able only to achieve a fore line vacuum of 50 microns even after the oil in the pump was changed.

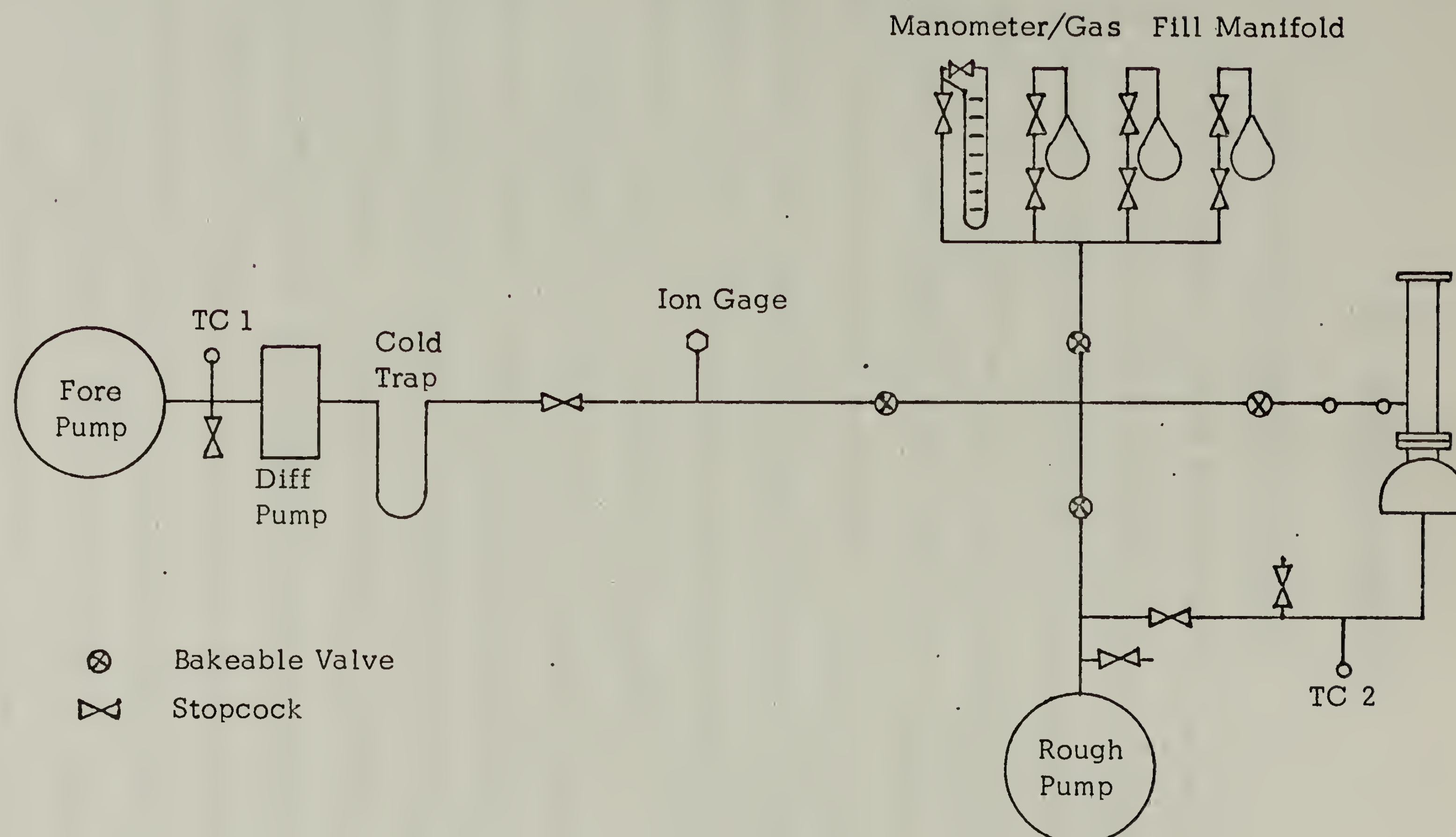

Figure 4. Vacuum system schematic

III. SPEAKER CALIBRATION

A. SPEAKER CHARACTERISTICS IN VACUUM

The characteristics of the electrodynamic speaker in an enclosure under vacuum or low pressure conditions were quite different from those at atmospheric pressure. The frequency response of the speaker varied greatly. This condition was partly due to the fact that under vacuum there is very little damping of the speaker cone. Therefore, the amplitude of the cone oscillations was greater. Secondly, the chemicals impregnated in the speaker cone which keep the cone pliable outgassed and after a period of time, a substantial amount of these chemicals was removed from the cone, thus changing its properties.

Additionally, the acoustic pressure created by the speaker within the discharge tube was extremely frequency sensitive due to the creation of standing waves and resonance conditions in the discharge tube. It appeared that resonance occurred at a frequency of 170 Hz. The velocity of sound in nitrogen gas under conditions similar to those of this project was measured by Subertova [8] to be approximately 270 m/s. With this sound velocity, the length of the discharge tube corresponded to a half wavelength at 170 Hz. As the acoustic frequency was varied on either side of 170 Hz, the acoustic pressure was reduced sharply. Since the perturbation current created by the acoustic wave was a function of acoustic pressure, it was readily apparent that the speaker had to be calibrated in some manner in terms of acoustic pressure.

Initially a condenser microphone was considered as a device to measure the acoustic pressure. However, previous experimentation at NPS by Carretta and Moore with a condenser microphone under vacuum conditions indicated many shortcomings with this device including necessary circuit modification.

B. MOBILITY-LIMITED THERMIONIC DIODE

The possibility of using a mobility-limited diode as a microphone was reported by Dayton [10] and recently Tripp [9] used diodes with success in plasma-acoustic research.

It was shown in Ref. [9] that the plate current is directly proportional to plate to cathode voltage and is inversely proportional to pressure, that is

$$I = CP^{-k_1} V^{k_2}$$

where C, k_1, and k_2 are empirically determined.

The diode used consisted of a tantalum cylindrical plate 1 cm long and 1 cm in diameter. The cathode filament was made of thoriated tungsten. The diode leads were mounted in a glass seal with connecting wire leads running through an 8mm glass tube which allowed the diode to be inserted into the discharge tube through a Swagelock tube fitting in the top cap. At first, difficulty was experienced with the diode because of sputtering. Sputtering occurred when positive ions striking the cathode caused ejection of metal from the cathode. This ejected metal deposited itself on the glass insulation surrounding the diode

leads and eventually caused a short circuit between the leads. This condition was eventually prevented by having the diode leads separate approximately 1.5 inches above the diode plate so that the glass seal containing all three leads was out of range of ejected metal from the cathode.

The circuit shown in Fig. 5 was used to calibrate the diode. A Power Designs model 36100R dc power supply was used to maintain 10 volts across the filament which provided an operating temperature of approximately 1750°C as was measured with an optical pyrometer. Plate voltage was supplied by a Power Designs model HV-1565 regulated dc power supply. Plate current was measured with a Keithley 600B electrometer which had an internal impedance of only 10 ohms. For each ambient nitrogen gas pressure in the discharge tube, the plate voltage was varied from 11 to 16 volts in one volt increments and the plate current recorded. The nitrogen gas pressure was changed from zero to 11 torr in one torr increments. The diode calibration curves appear in Fig. 6 together with the values of k_1 and k_2 as determined by a least squares fit to the curves.

C. SPEAKER CALIBRATION PROCEDURE AND RESULTS

The diode circuit used for calibration of the electrodynamic speaker is shown in Fig. 7. Tripp [9] showed that the diode sensitivity is given by:

$$S = \frac{k_1 \ V_{DC}}{P \ (1 + k_2 \ \frac{V_{DC}}{V - V_{DC}})} .$$

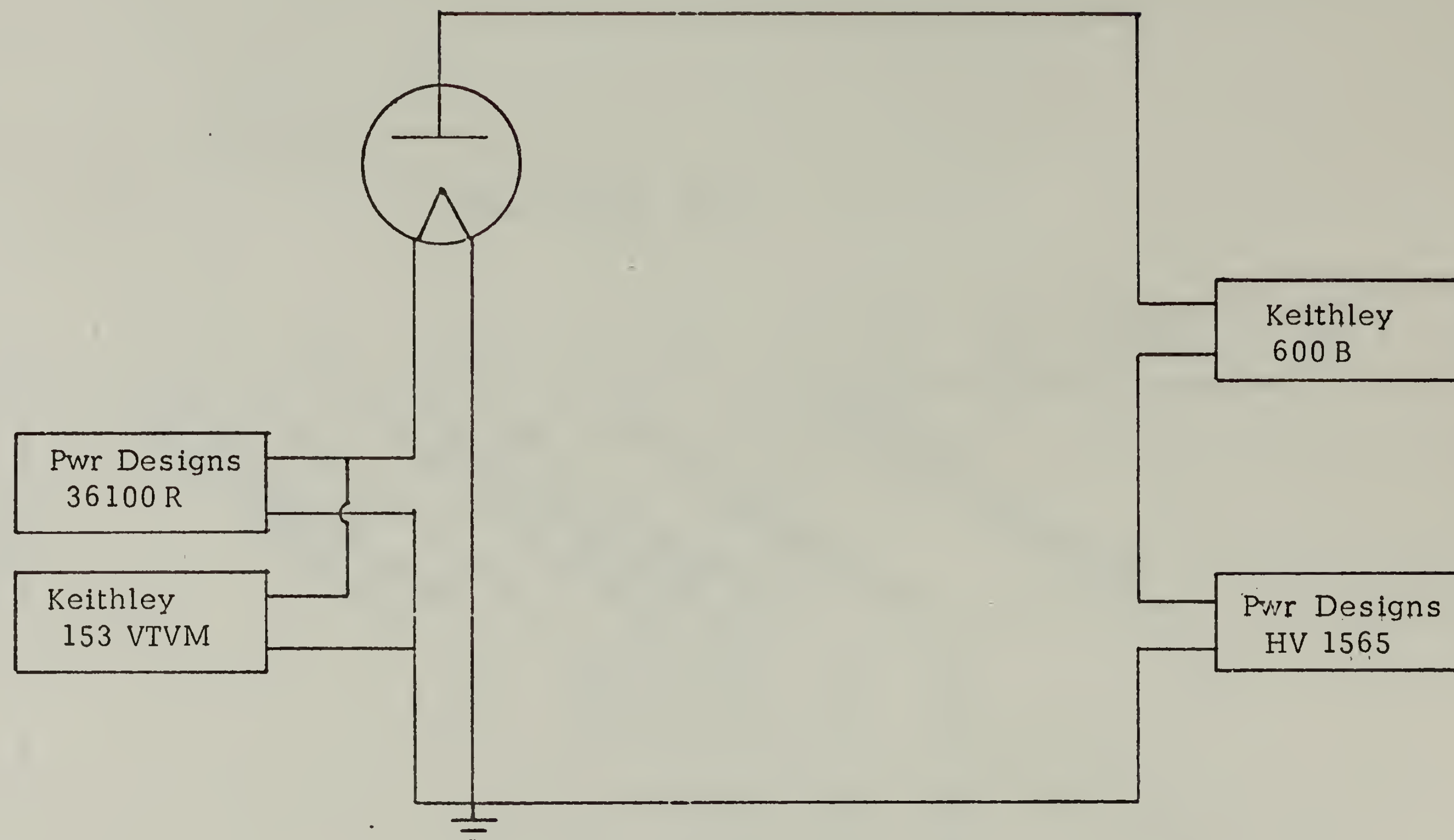

Figure 5. Diode calibration circuit

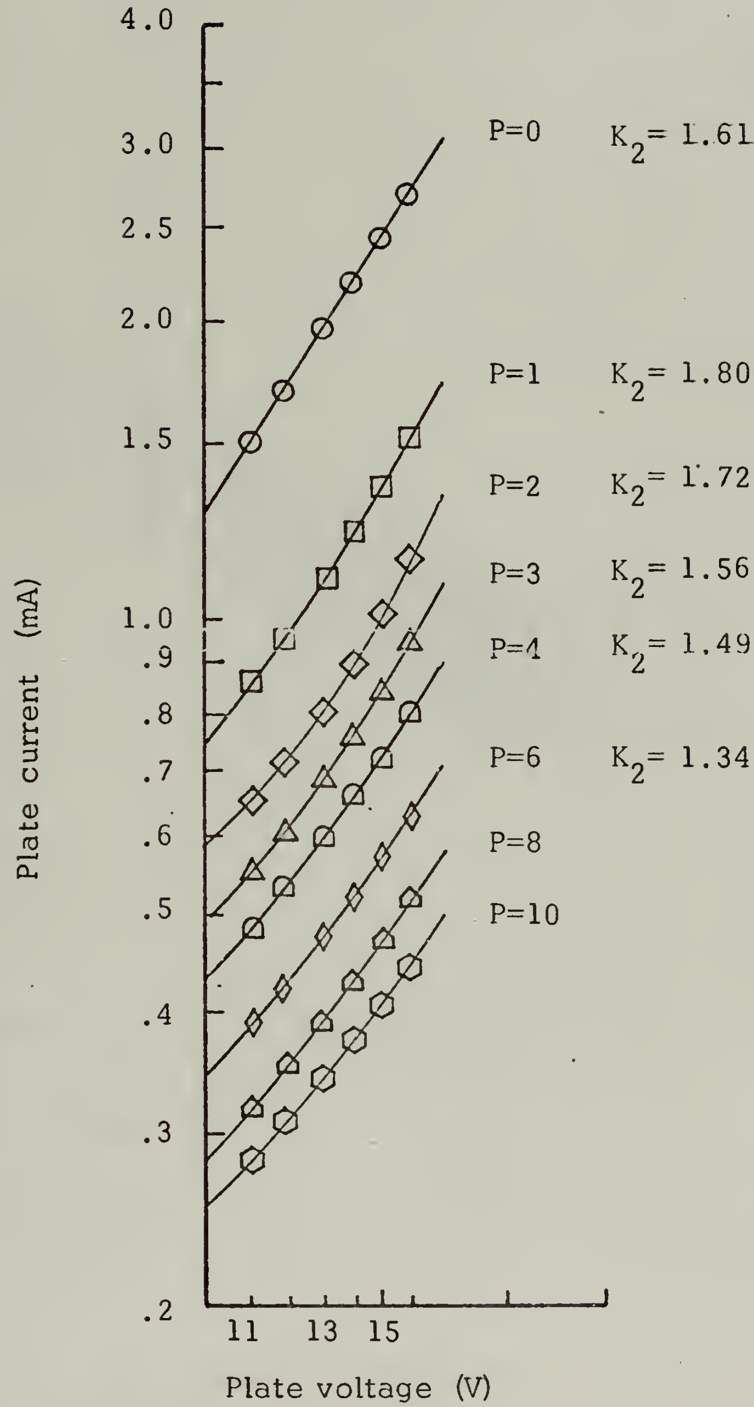

Figure 6a. Plate current vs. plate voltage at constant pressure

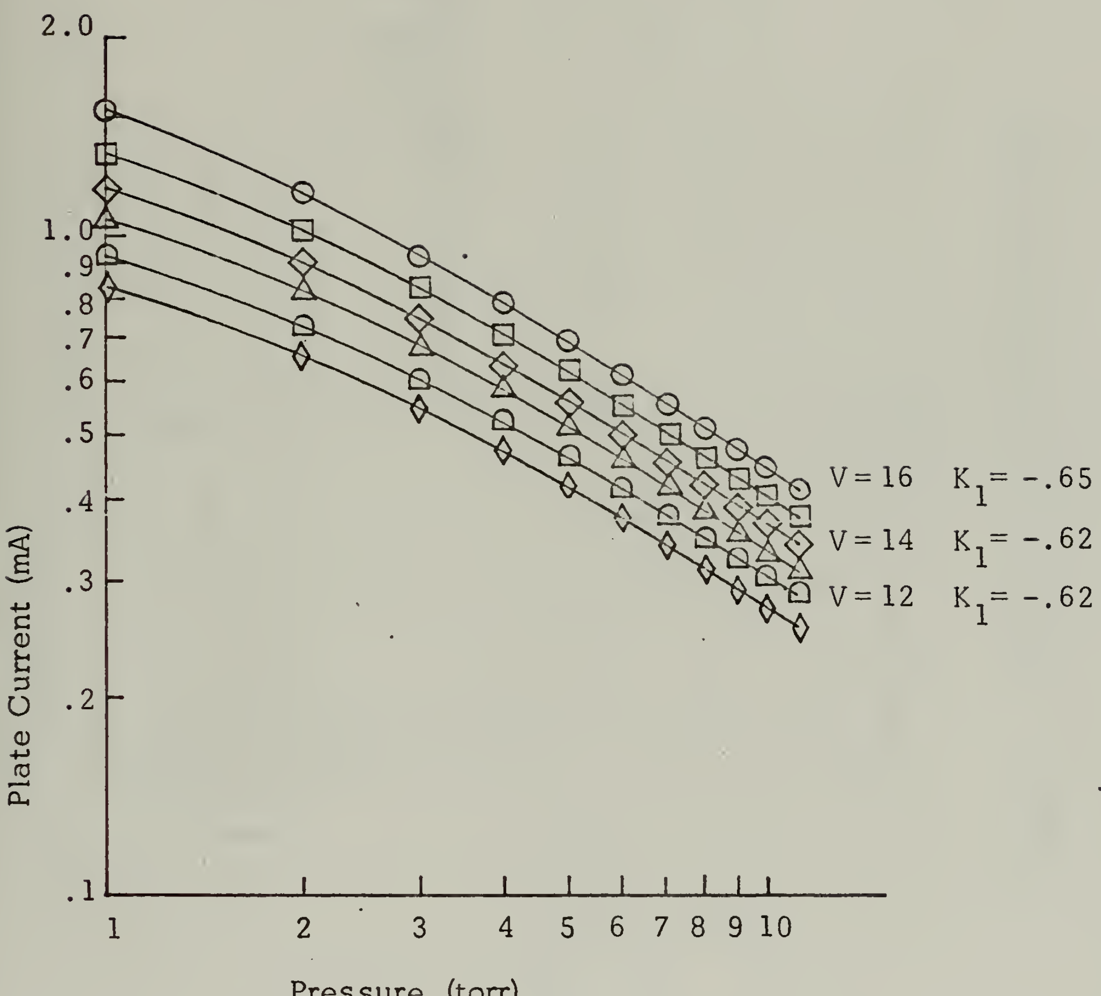

Figure 6b. Plate current vs. pressure at constant plate voltage

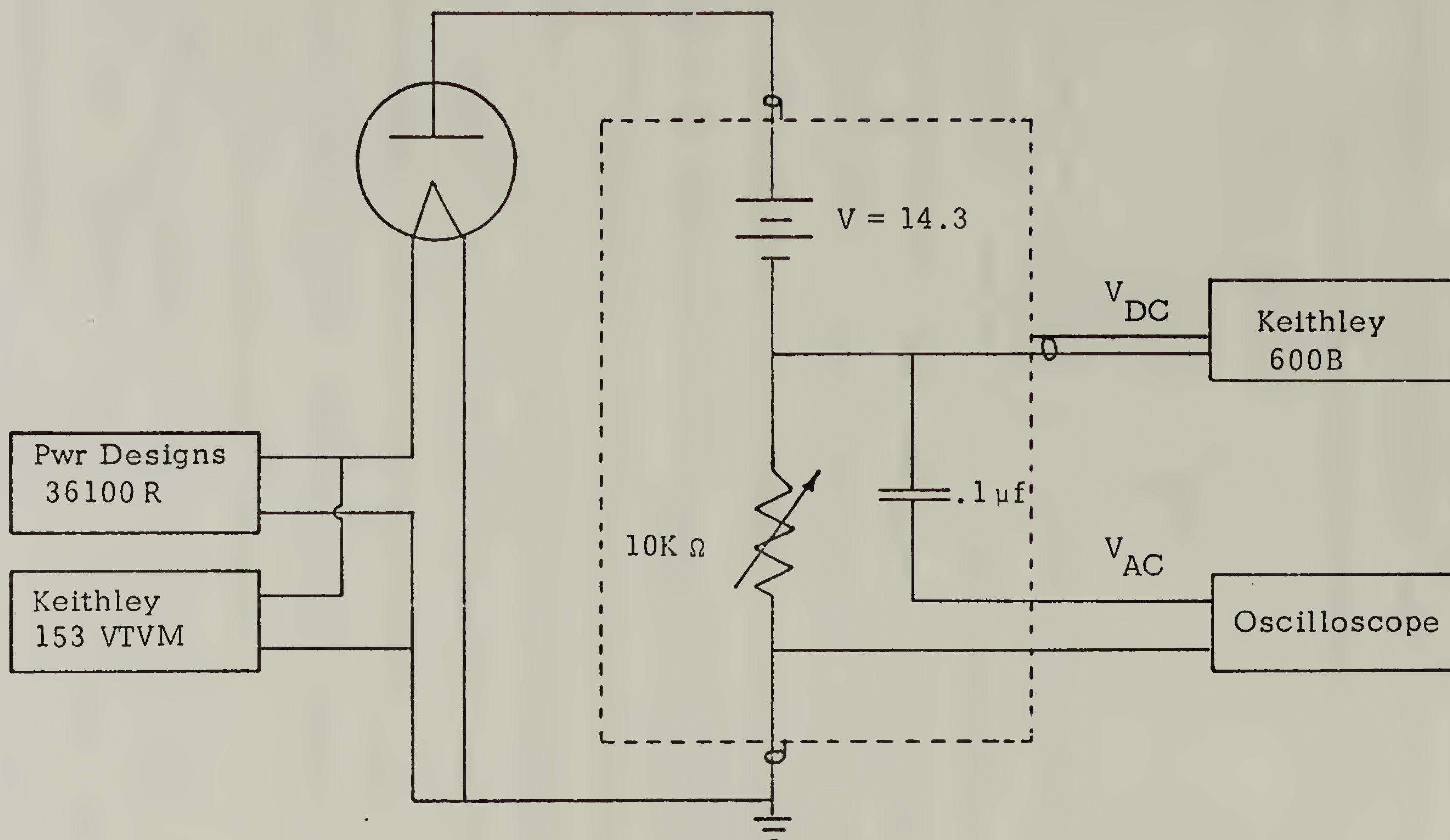

Figure 7. Diode circuit for speaker calibration

where P was the ambient gas pressure in the discharge tube, V was the supply voltage to the plate, and V_{DC} was the dc component of the output voltage and was determined by the variable 10K ohm resistor. Tripp [9] also showed that an acoustic pressure, $\tilde{P}$, created by an acoustic wave is given by:

$$\tilde{P} = \frac{V_{AC}}{S}$$

It was decided to make all measurements at one point in the discharge tube and a position 22 inches above the speaker was chosen. The only significance to this location was that it was well within the positive column region of the glow discharge. It was also decided to remove the diaphragm which separated the discharge tube and speaker. This step was taken because the diaphragm did not pass all frequencies and those frequencies that were passed were greatly attenuated. The diaphragm removal caused a reduction in the maximum obtainable vacuum in the discharge tube to 1×10^{-6} torr. The diode was very susceptible to contamination so that the noise created by the diode was increased by outgassing of the speaker. However, with the diaphragm removed, the signal-to-noise ratio of the diode was greater.

The diode filament was again operated at 10 volts, and V_{DC} was set at 3 volts. Using the equations in this section, values of V_{AC} were calculated for desired acoustic pressures as listed below in Table 1.

Acoustic Pressure $\tilde{P}$	Ambient Pressure P	V_{AC}
.00085	1	1.06
.0011	1	1.41
.0014	1	1.77
.004	1	5.00
.004	2	2.54
.004	3	1.74
.004	4	1.33
.004	5	1.09

TABLE 1

Data were then taken for a range of frequencies at each ambient pressure by adjusting the speaker gain to achieve the values of V_{AC} in Table 1. The speaker gain was determined by measuring the voltage drop across the speaker impedance with a Ballantine 311 VTVM. This speaker calibration data appears in Table 2.

In order to get some idea of the acoustic pressure profile in the discharge tube created by an acoustic wave, the diode was positioned at various points in the tube and the acoustic pressure measured with an ambient nitrogen gas pressure of 1.0 torr. This acoustic pressure profile appears in Fig. 8.

V_{spkr} for $\tilde{P}$ =

P	1 TORR				2 TORR	3 TORR	4 TORR	5 TORR
f	$\tilde{P}$=.00085	$\tilde{P}$=.0011	$\tilde{P}$=.0014	$\tilde{P}$=.004	$\tilde{P}$=.004	$\tilde{P}$=.004	$\tilde{P}$=.004	$\tilde{P}$=.004
250	3.10	4.30	5.80	--	5.40	3.00	2.00	1.50
230	2.14	2.80	3.70	--	3.20	1.80	1.20	0.94
210	1.35	1.85	2.40	--	1.85	1.00	0.58	0.43
190	0.78	1.07	1.50	5.30	1.00	0.45	0.31	0.26
180	0.57	0.78	1.00	3.50	0.69	0.34	0.25	0.21
170	0.52	0.64	0.83	2.73	0.53	0.31	0.23	0.18
160	0.50	0.61	0.77	2.15	0.52	0.32	0.26	0.22
150	0.48	0.60	0.72	1.93	0.59	0.39	0.30	0.23
130	0.56	0.69	0.85	2.05	0.83	0.55	0.45	0.38
110	0.65	0.80	0.98	2.55	1.06	0.70	0.58	0.49
90	0.77	0.98	1.15	3.40	1.33	0.84	0.71	0.52
70	0.80	1.02	1.32	3.90	1.80	0.96	0.78	0.66
50	0.81	1.05	1.35	3.90	1.80	0.86	0.70	0.57

TABLE 2. Speaker calibration data in Nitrogen gas

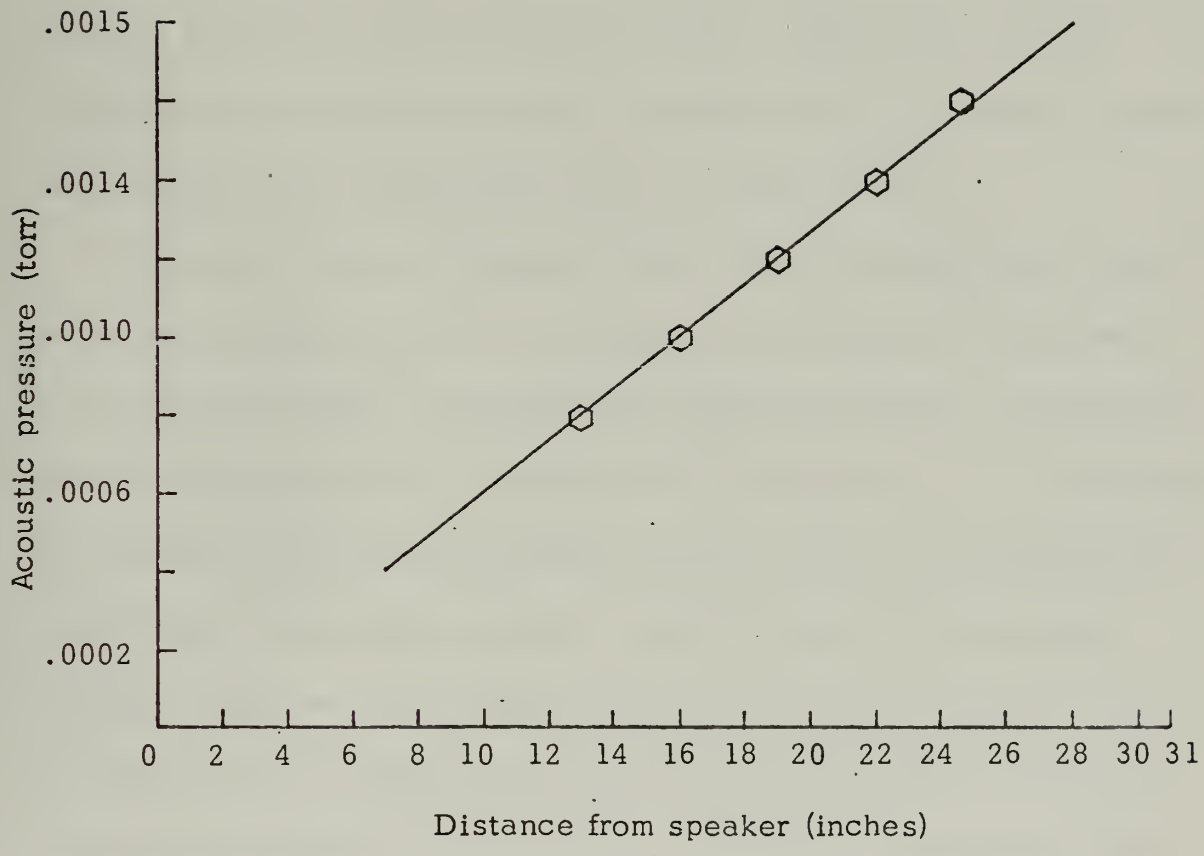

Figure 8. Acoustic pressure profile in discharge tube

IV. EXPERIMENTAL PROCEDURES AND RESULTS

A. CONSTRUCTION AND CALIBRATION OF ROGOWSKY RING

The primary diagnostic device used in this project was the Rogowsky Ring. The perturbation current in the glow discharge had associated with it a time-varying azimuthal magnetic field. This magnetic field induced an emf in the windings of a toroid (Rogowsky Ring) whose longitudinal axis was parallel to the perturbation current. This induced emf was amplified and measured and through calibration data for the coil, the emf was converted into perturbation current in microamperes.

Initially a Pearson Electronics model 310 wide band current transformer was used as a coil but this device proved not to be sufficiently sensitive for the task. A supermalloy magnetic core with a permeability of 60,000 and dimensions 3.5 inches i.d., 4.5 inch o.d., 1.0 inch high was obtained. With a toroid winding machine the core was wound with 11,365 turns of 35 gauge varnished copper wire and was then double shielded. The first shield consisted of aluminum tape wrapped around the coil with a small slit on the inside circumference which prevented currents from flowing in the shielding in a direction perpendicular to the magnetic flux. The coil was then wrapped in Teflon tape and then placed in a brass case which again had an opening along the inside circumference. A BNC connector was attached to the brass case. One lead from the toroid was soldered to the case and the other lead to the BNC connector.

Using the circuit shown in Fig. 9, a known current as measured using a precision 20Kohm resistor with a Ballantine VTVM was passed through the center of the toroid. The induced emf in the toroid was amplified with a PAR HR-8 lock-in amplifier utilizing a type A preamp. The current magnitude and frequency were varied and plots of current versus induced voltage at constant frequency were made. These plots constituted the calibration data for the Rogowsky Ring shown as Fig. 10. The sensitivity of this device ranged from .227 to 1.71 uV/uA for frequencies from 250 Hz to 50 Hz respectively. In conjunction with the lock-in amplifier, the Rogowsky Ring was able to detect a perturbation current-produced magnetic field of the order of 10^{-11} Wb/m^2.

B. PROCEDURE

Once speaker calibration was completed, the diode was removed from the discharge tube and the anode installed. The discharge tube was allowed to pump down for several days and an ultimate vacuum of 8×10^{-6} torr was achieved. Nitrogen gas was admitted to the discharge tube at a pressure of 1 torr. A glow discharge was established and the perturbation current was measured for an acoustic pressure of .00085 torr as the acoustic frequency and dc discharge current were varied. This same procedure was carried out for acoustic pressures of .0011, .0014, and .004 torr at 1 torr ambient pressure. The ambient pressure was then increased to 2, 3, 4, and 5 torr and the perturbation current was measured for an acoustic pressure of .004 for various frequencies and dc discharge currents. The results of these measurements appear in figures 11 through 27.

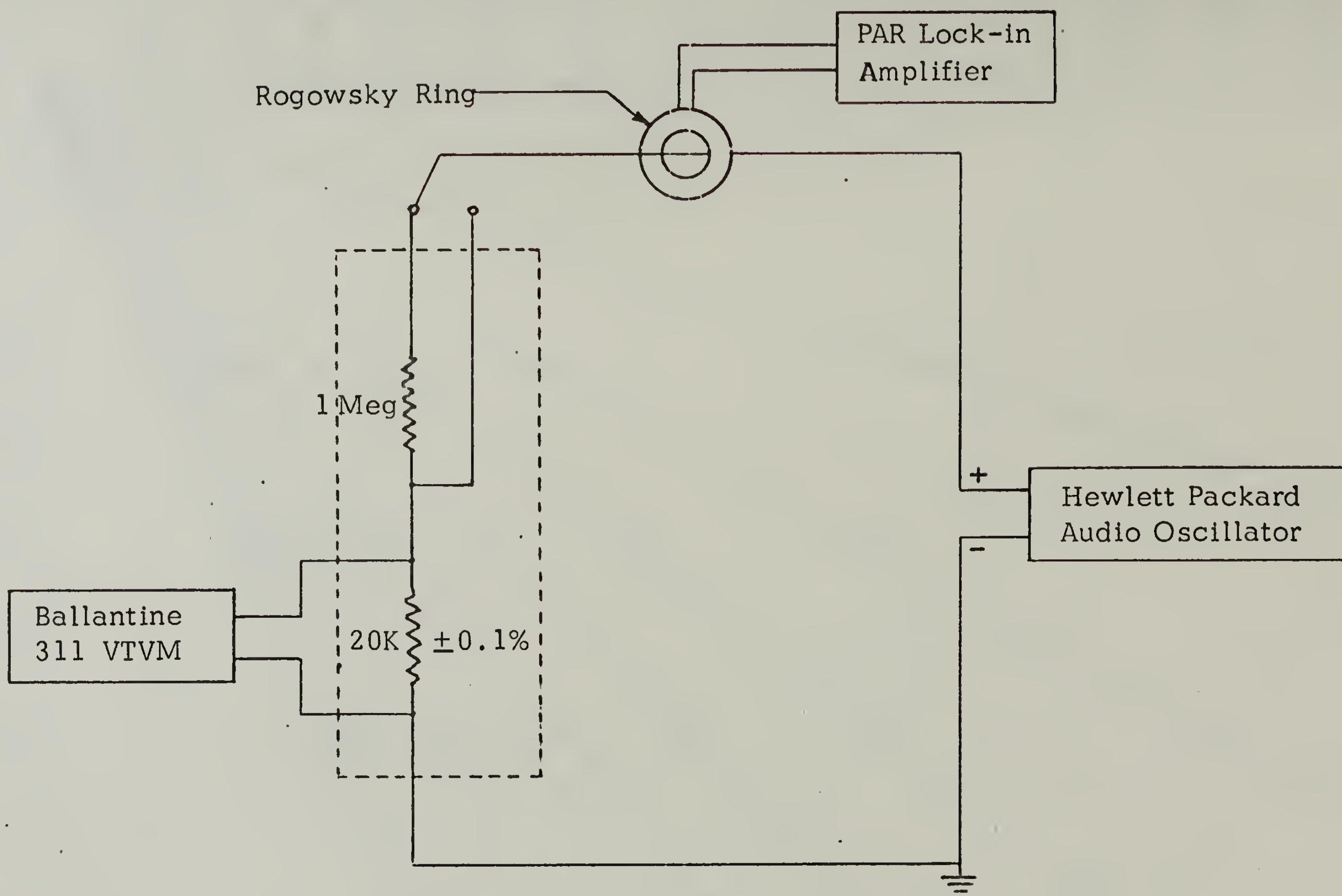

Figure 9. Rogowsky Ring calibration circuit.

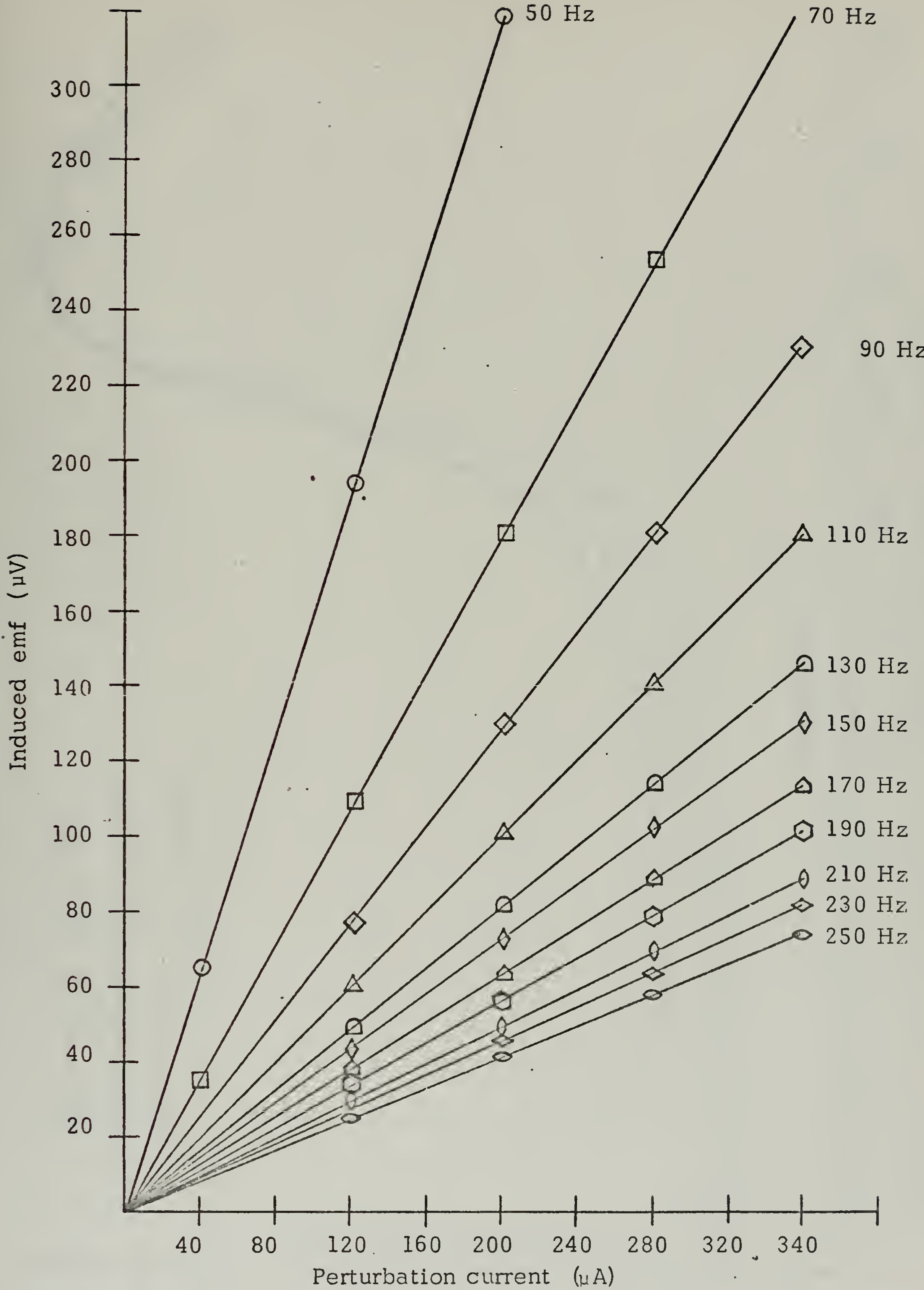

Figure 10. Rogowsky Ring calibration curves

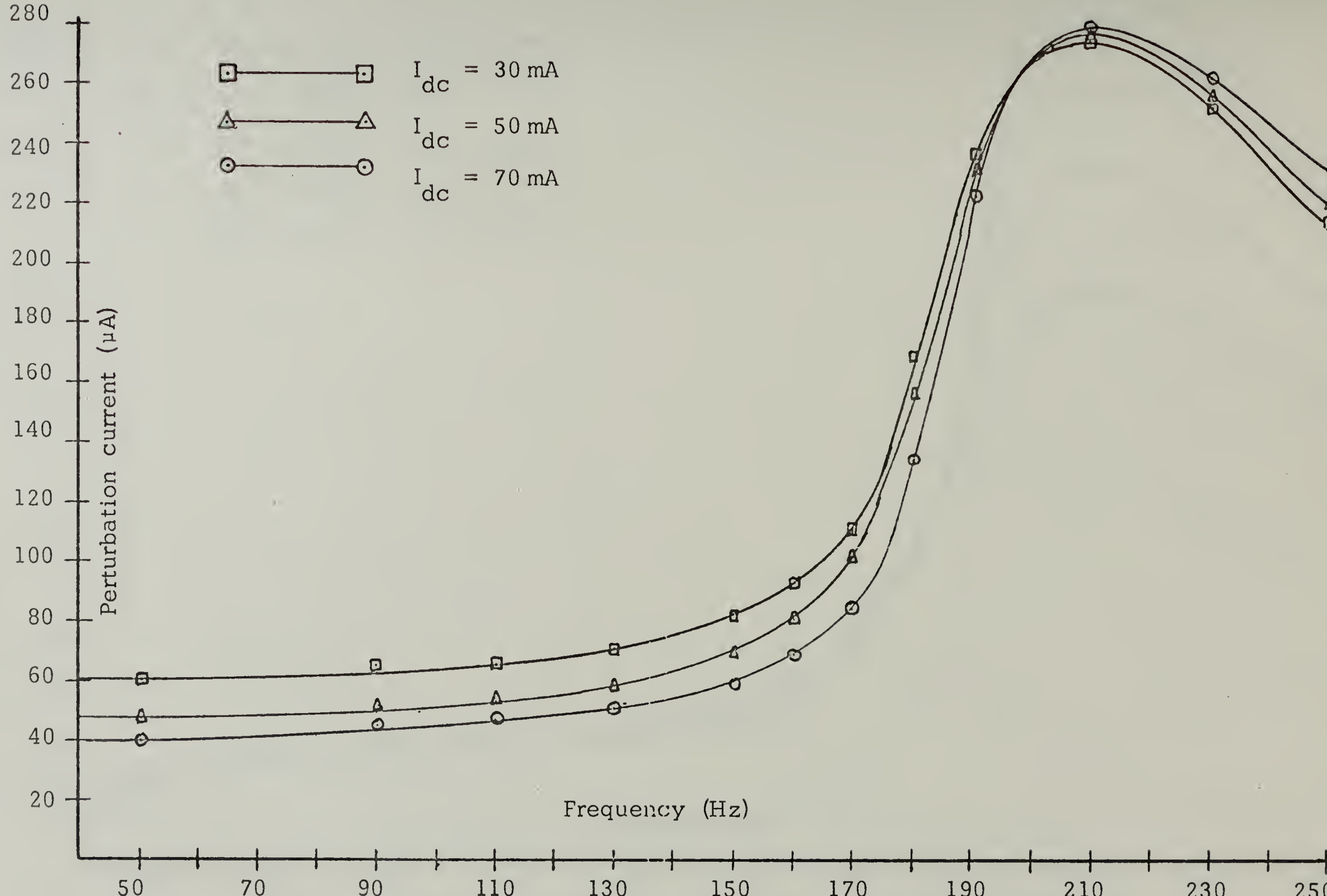

Figure 11. Perturbation current vs. frequency, $P = 2$ torr, $\tilde{P} = .004$ torr

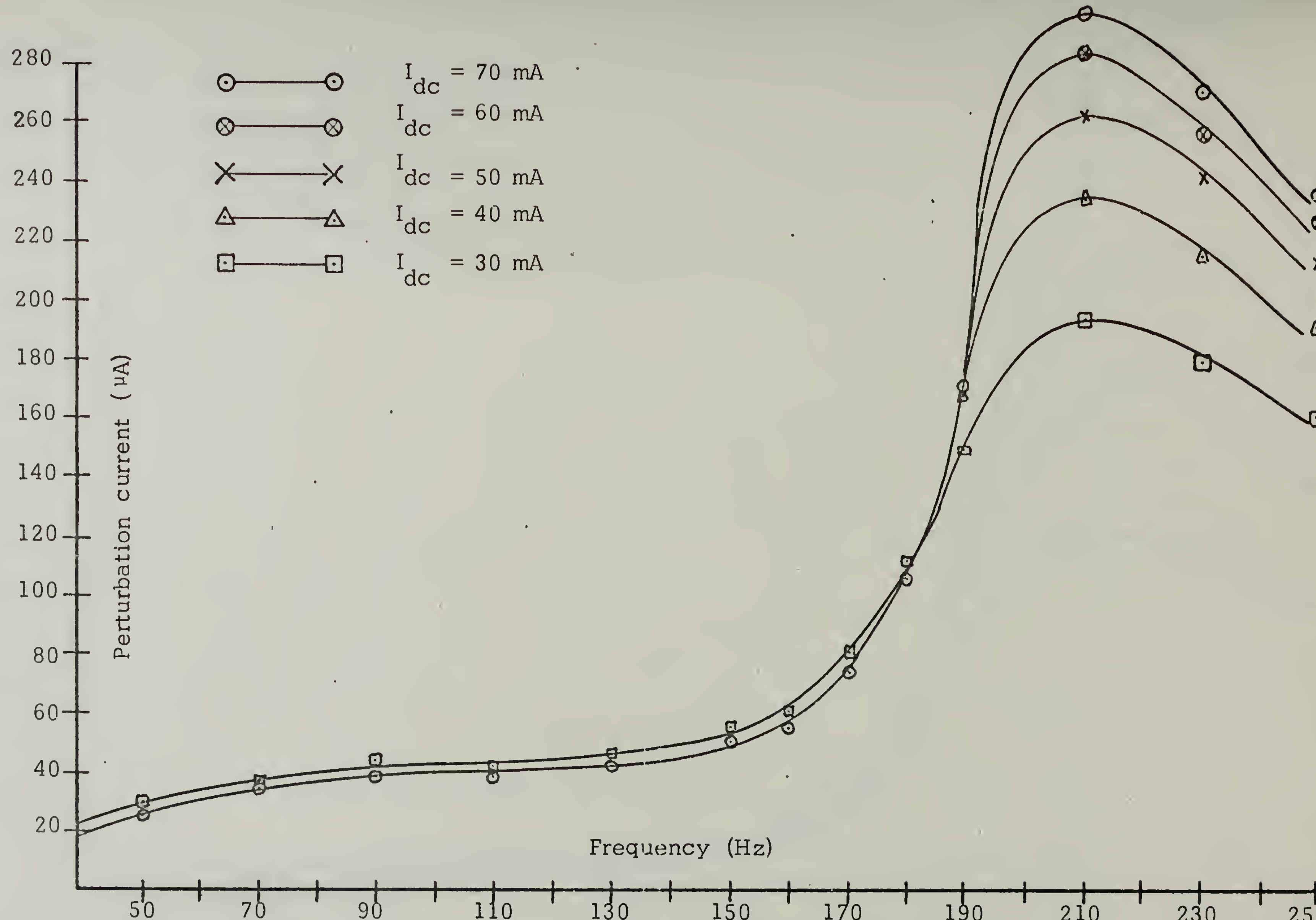

Figure 12. Perturbation current vs. frequency, P = 3 torr, $\tilde{P}$ = .004 torr

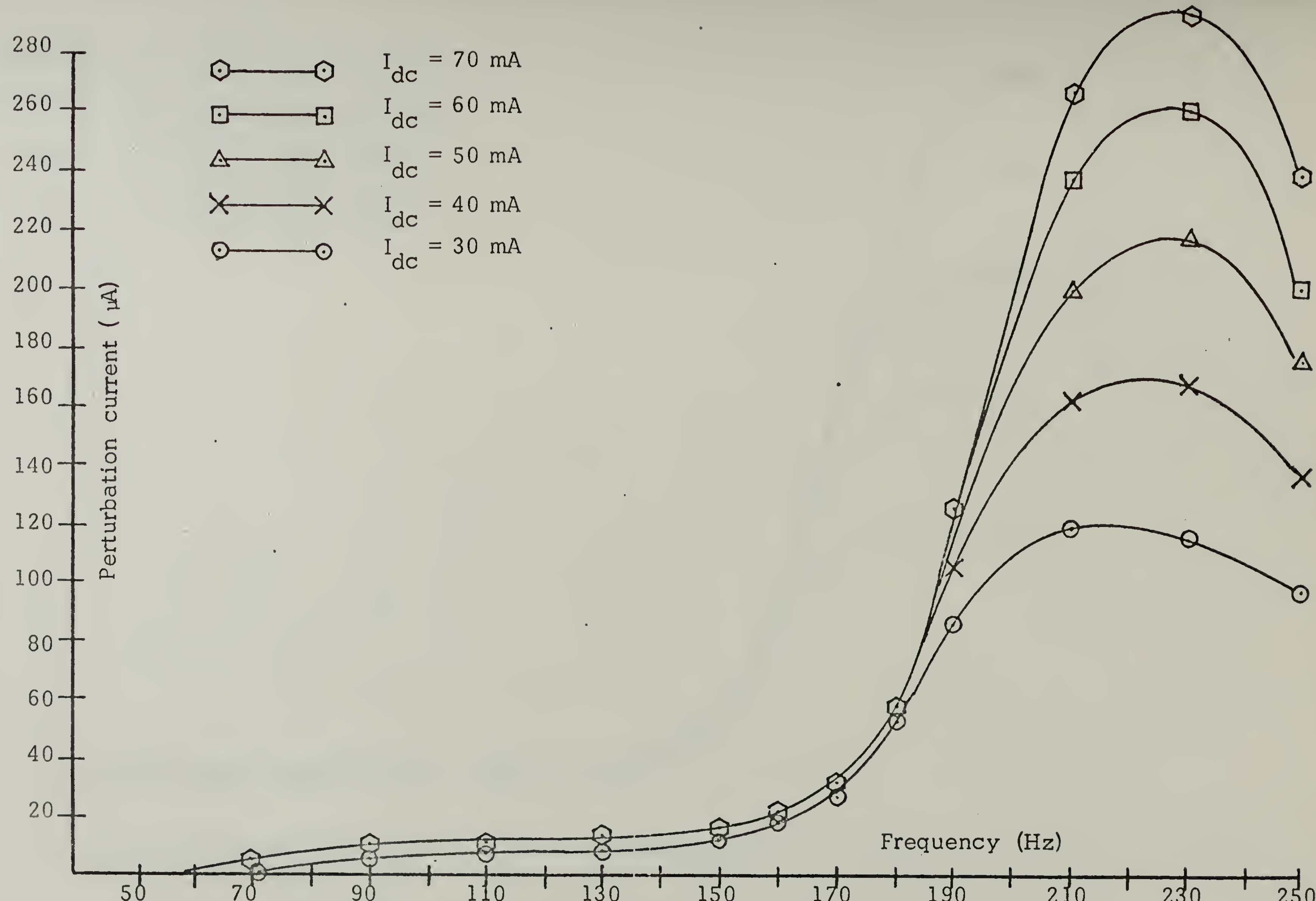

Figure 13. Perturbation current vs. frequency, P = 4 torr, $\tilde{P}$ = .004 torr

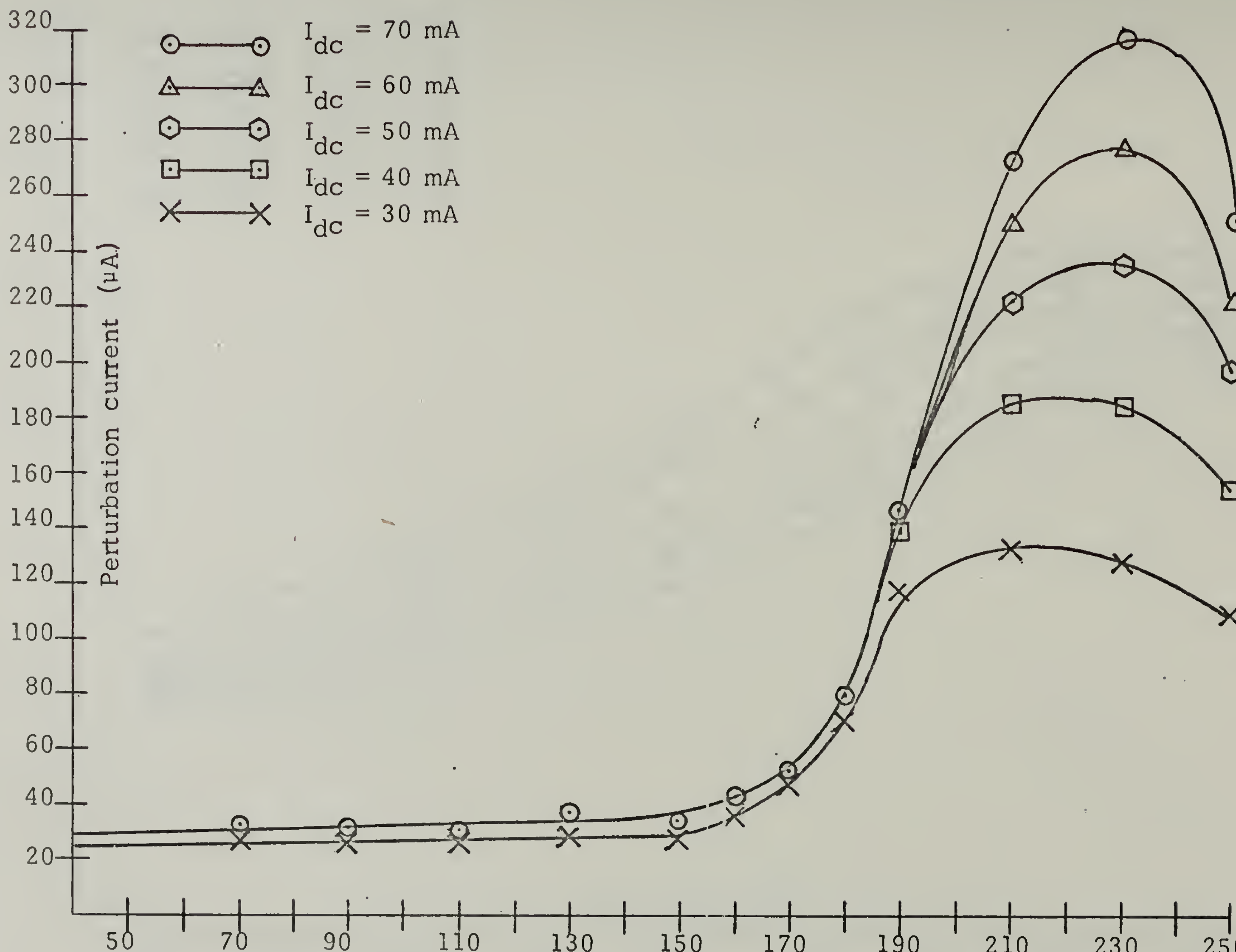

Figure 14. Perturbation current vs. frequency, P = 5 torr, $\tilde{P}$ = .004 torr

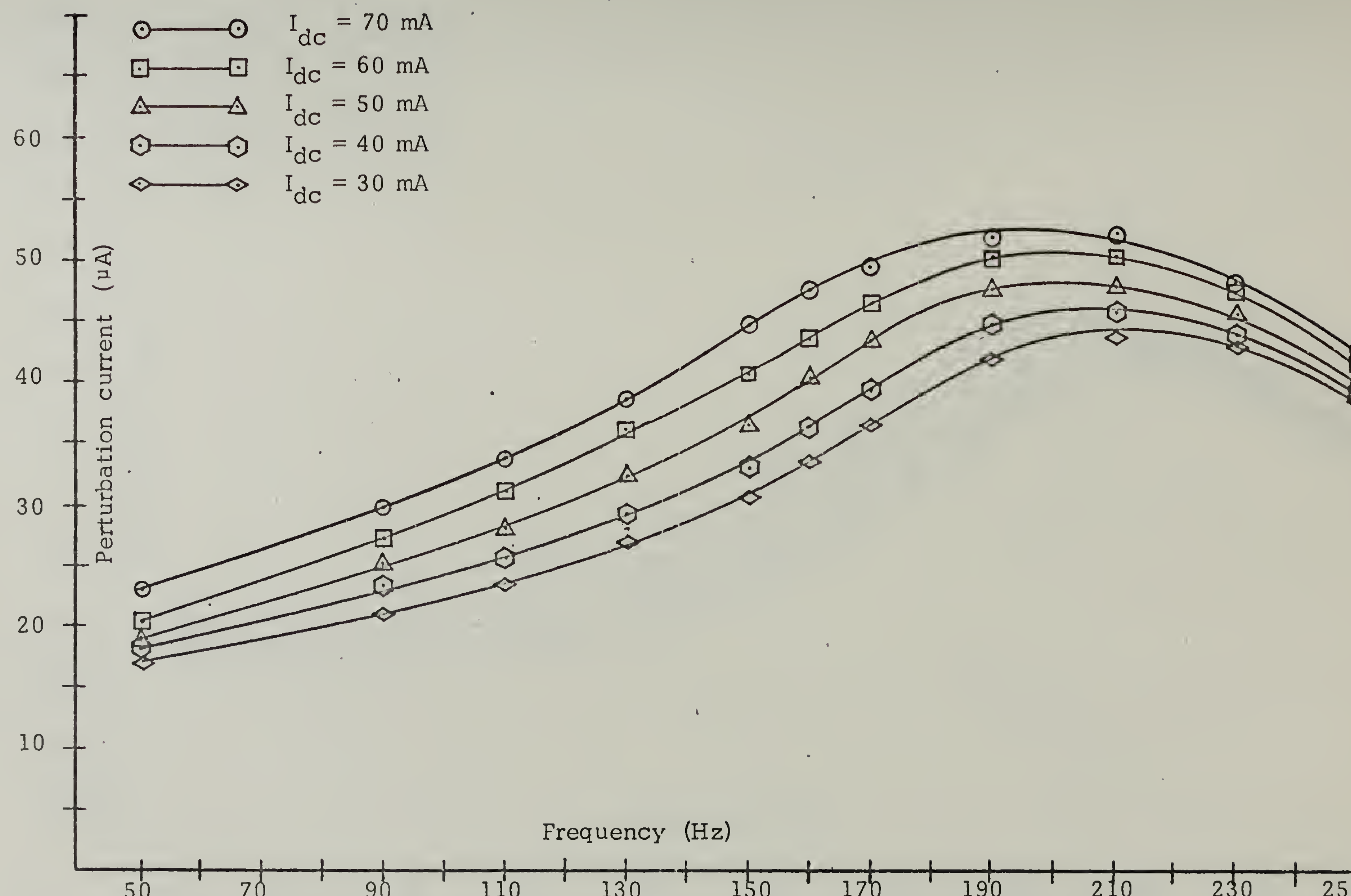

Figure 15. Perturbation current vs. frequency, P = 1 torr, $\tilde{P}$ = .00085 torr

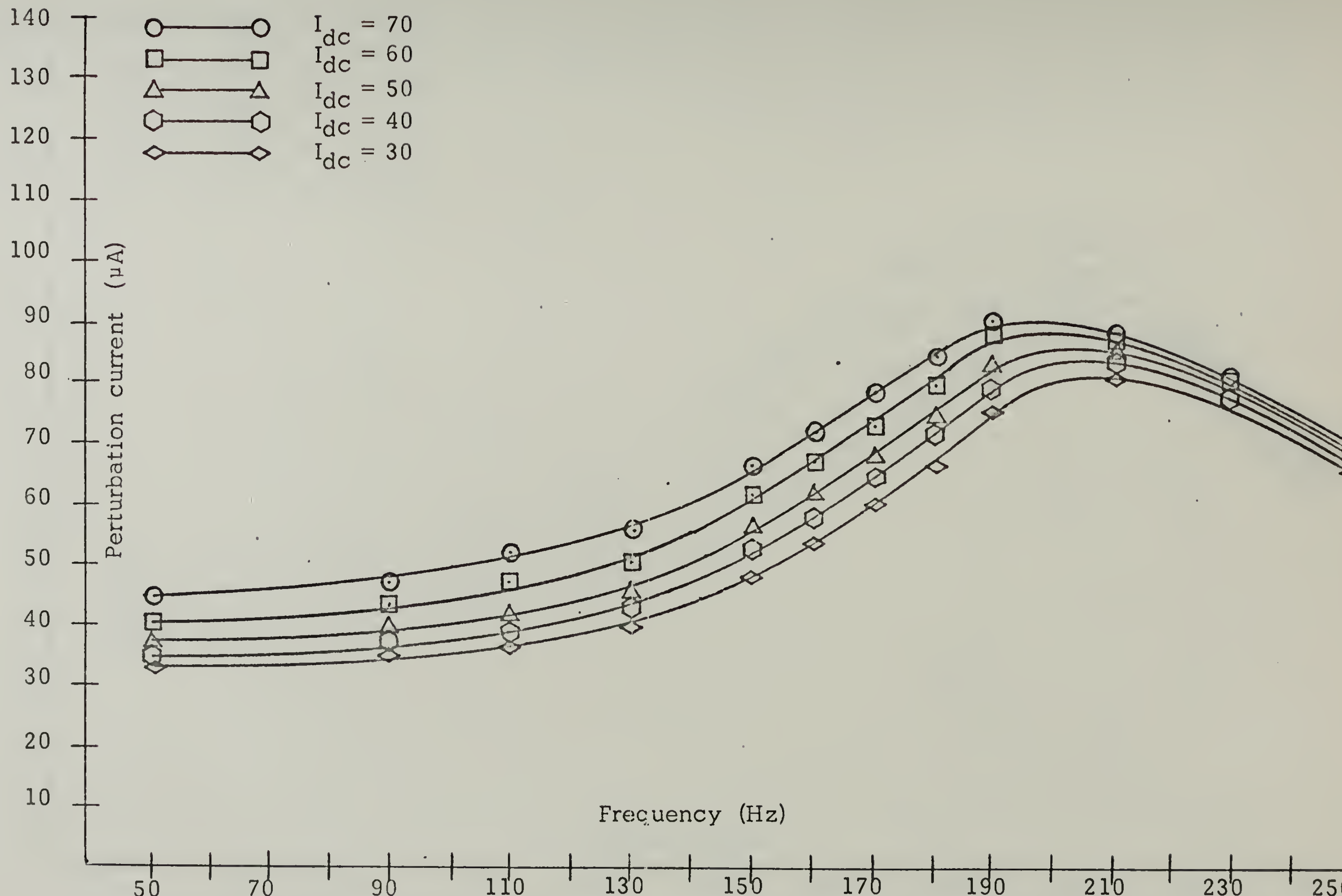

Figure 16. Perturbation current vs. frequency, P = 1 torr, $\tilde{P}$ = .0011 torr

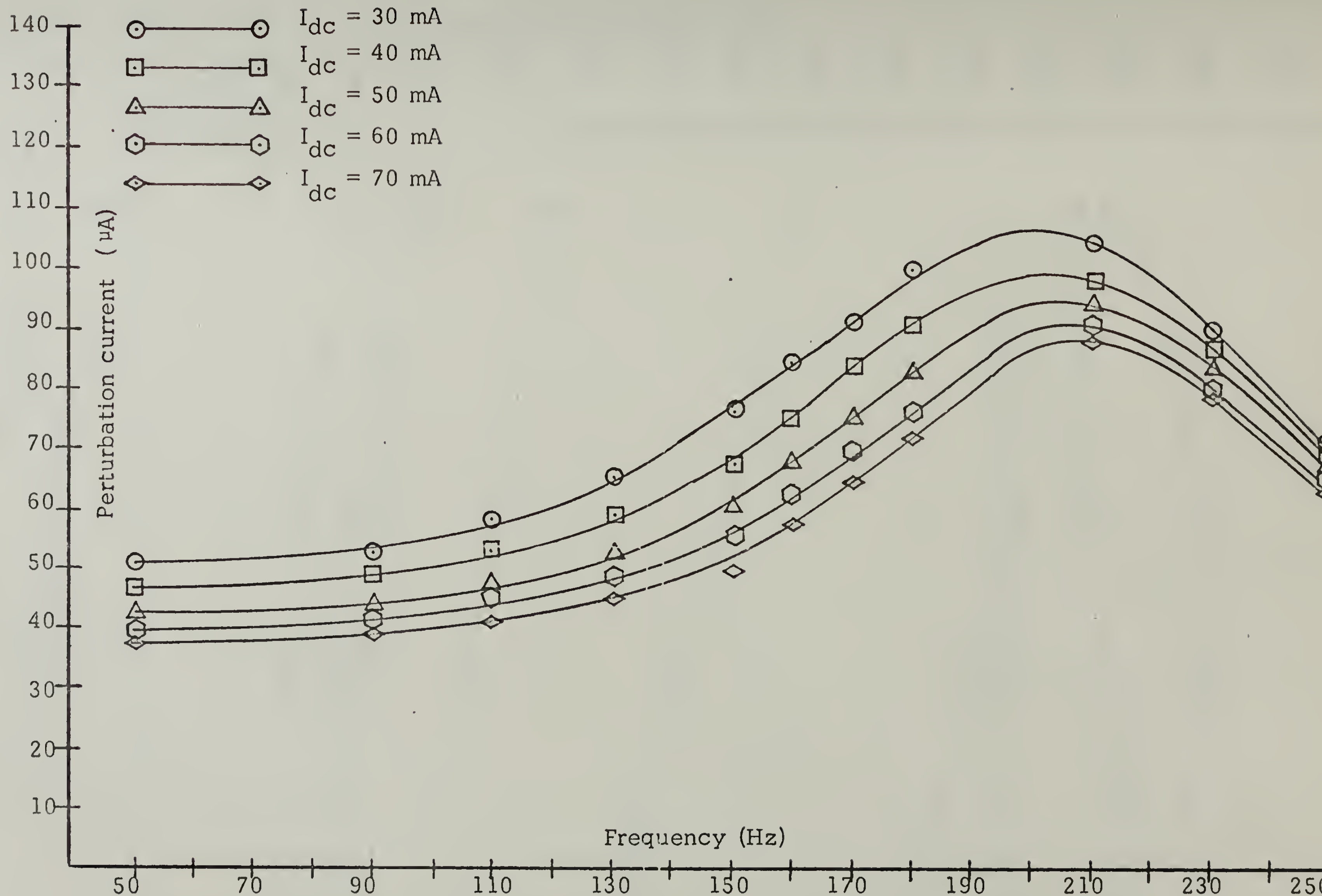

Figure 17. Perturbation current vs. frequency, P = 1 torr, $\tilde{P}$ = .0014 torr

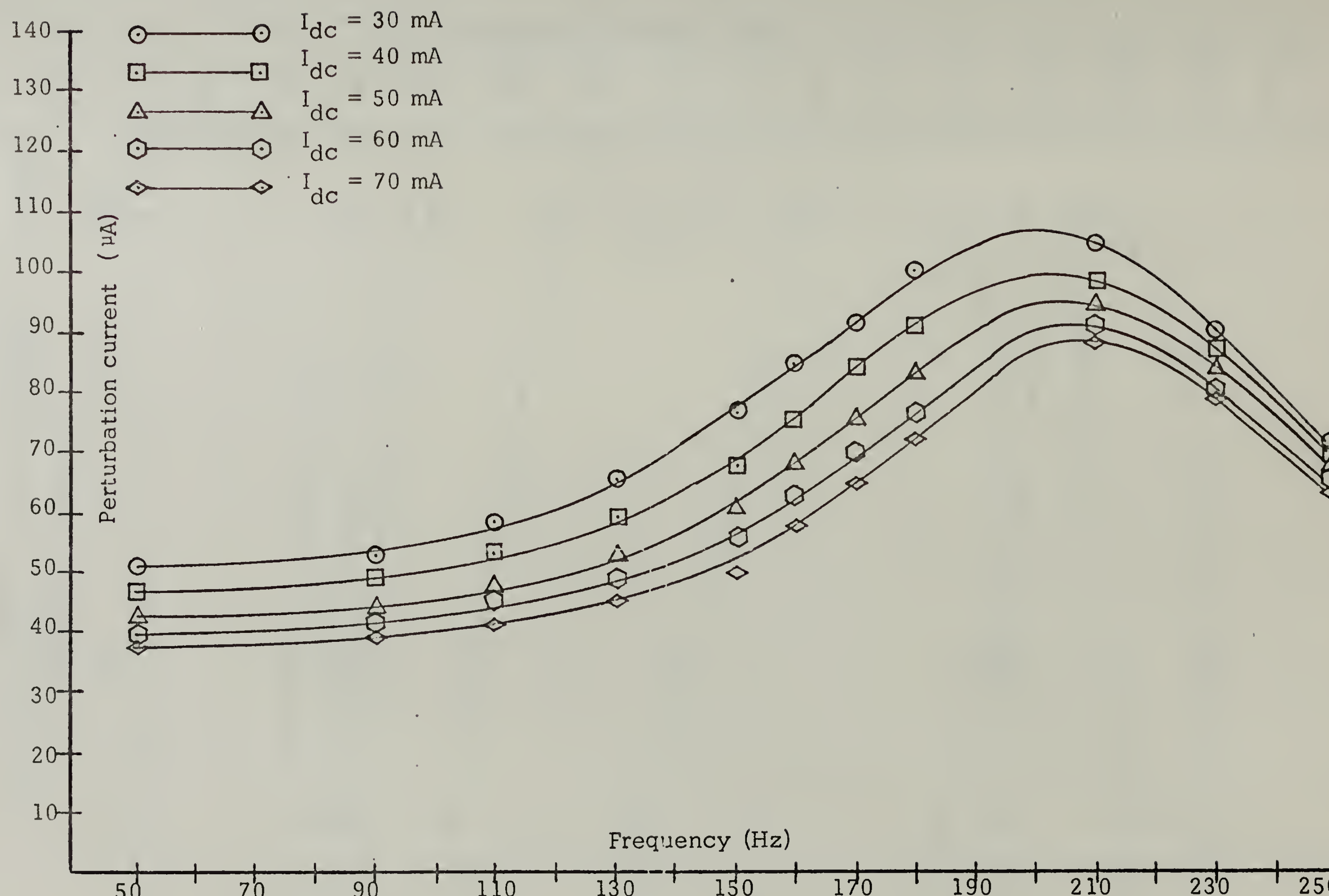

Figure 17. Perturbation current vs. frequency, P = 1 torr, $\tilde{P}$ = .0014 torr

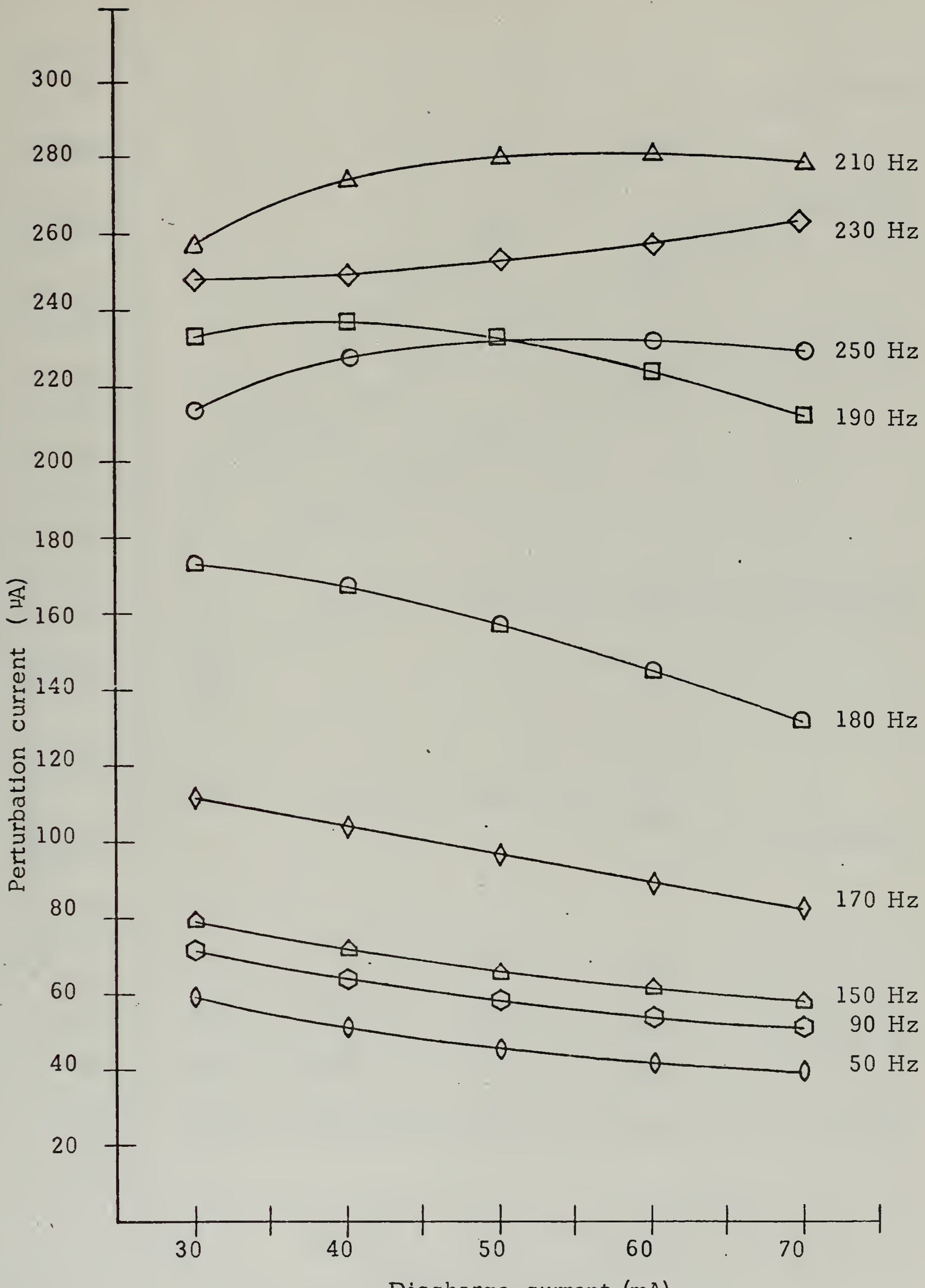

Figure 18. Perturbation current vs. discharge current
P = 2 torr, $\tilde{P}$ = .004 torr

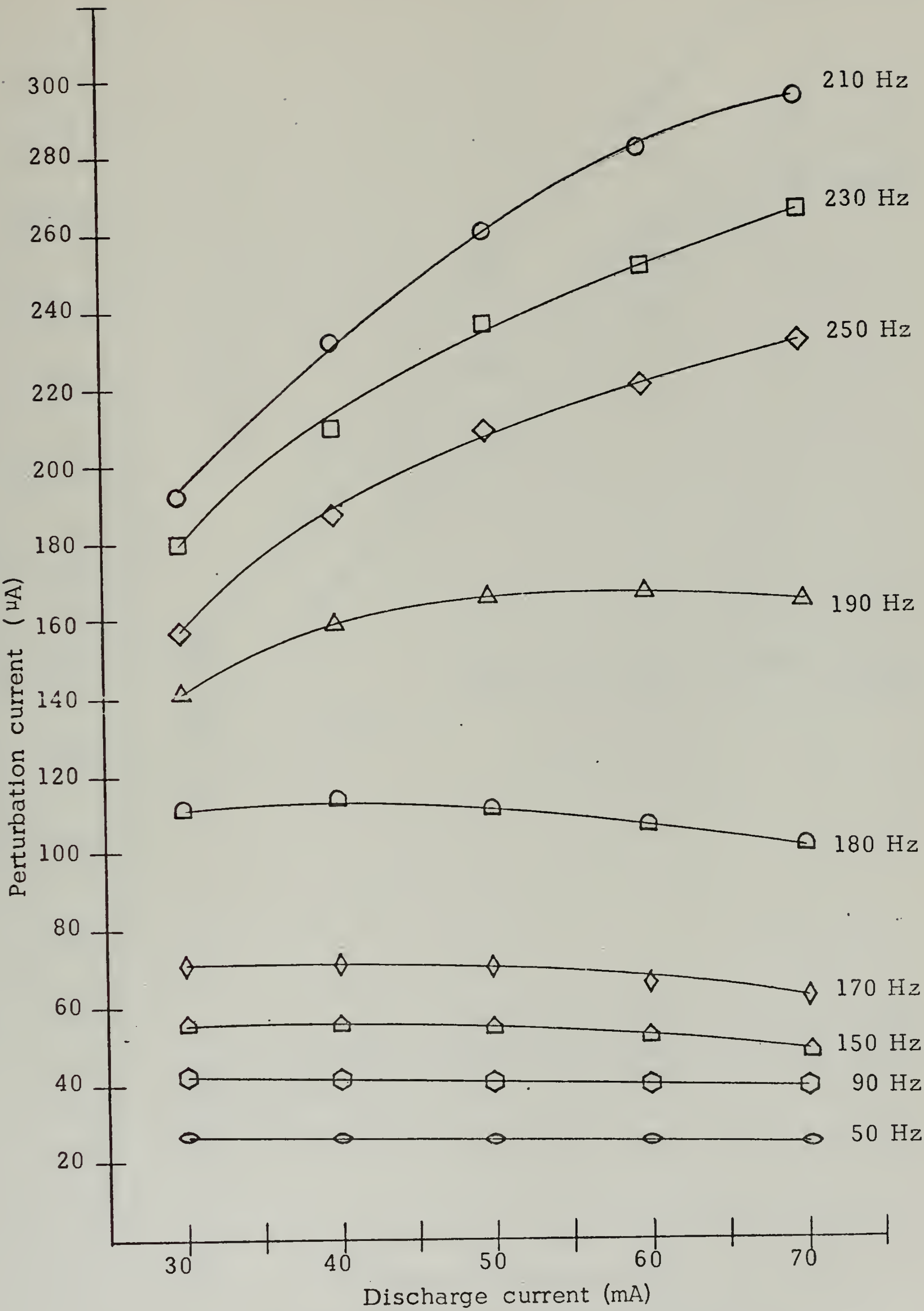

Figure 19. Perturbation current vs. discharge current
$P = 3$ torr, $\tilde{P} = .004$ torr

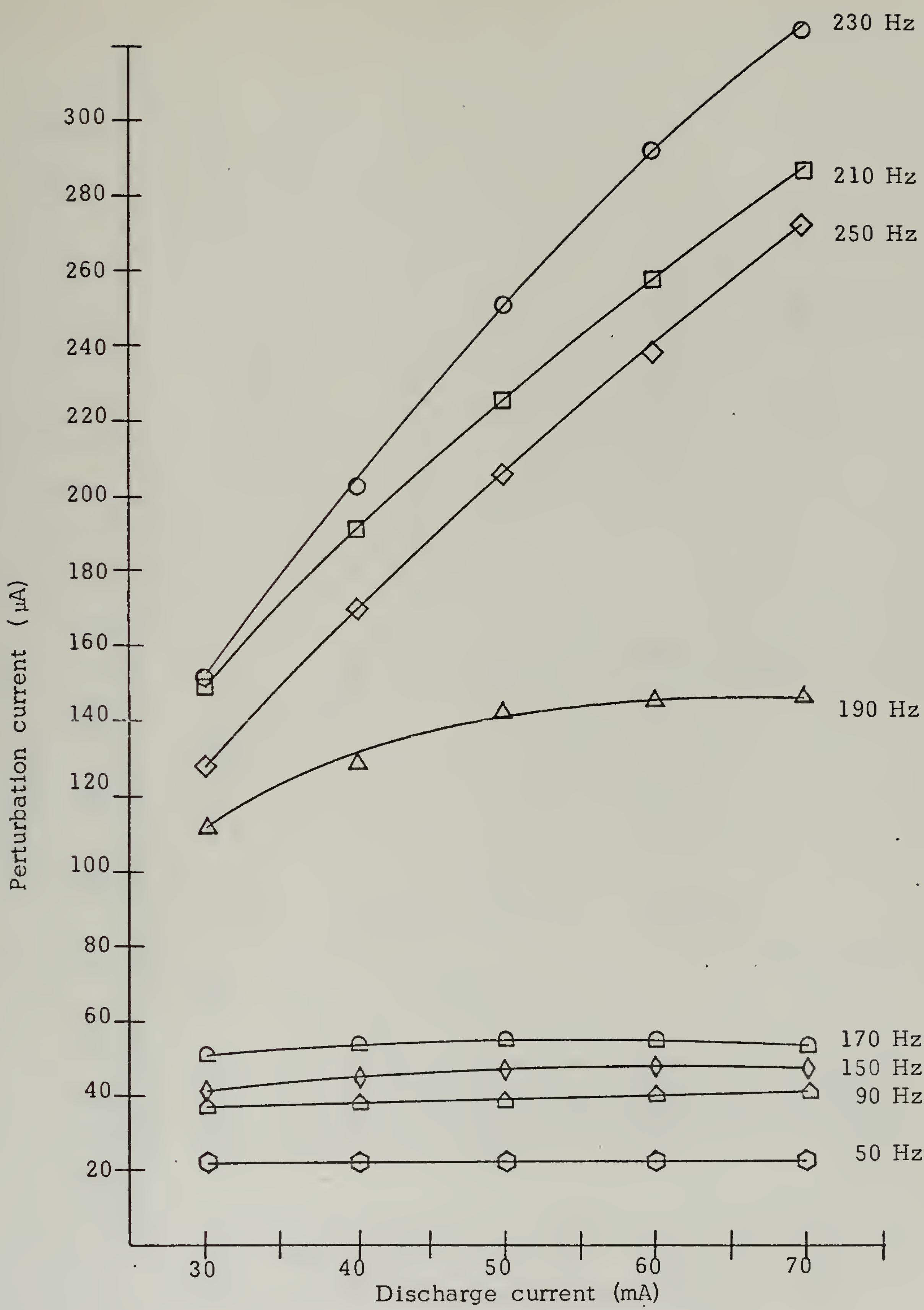

Figure 20. Perturbation current vs. discharge current
P = 4 torr, P̃ = .004 torr

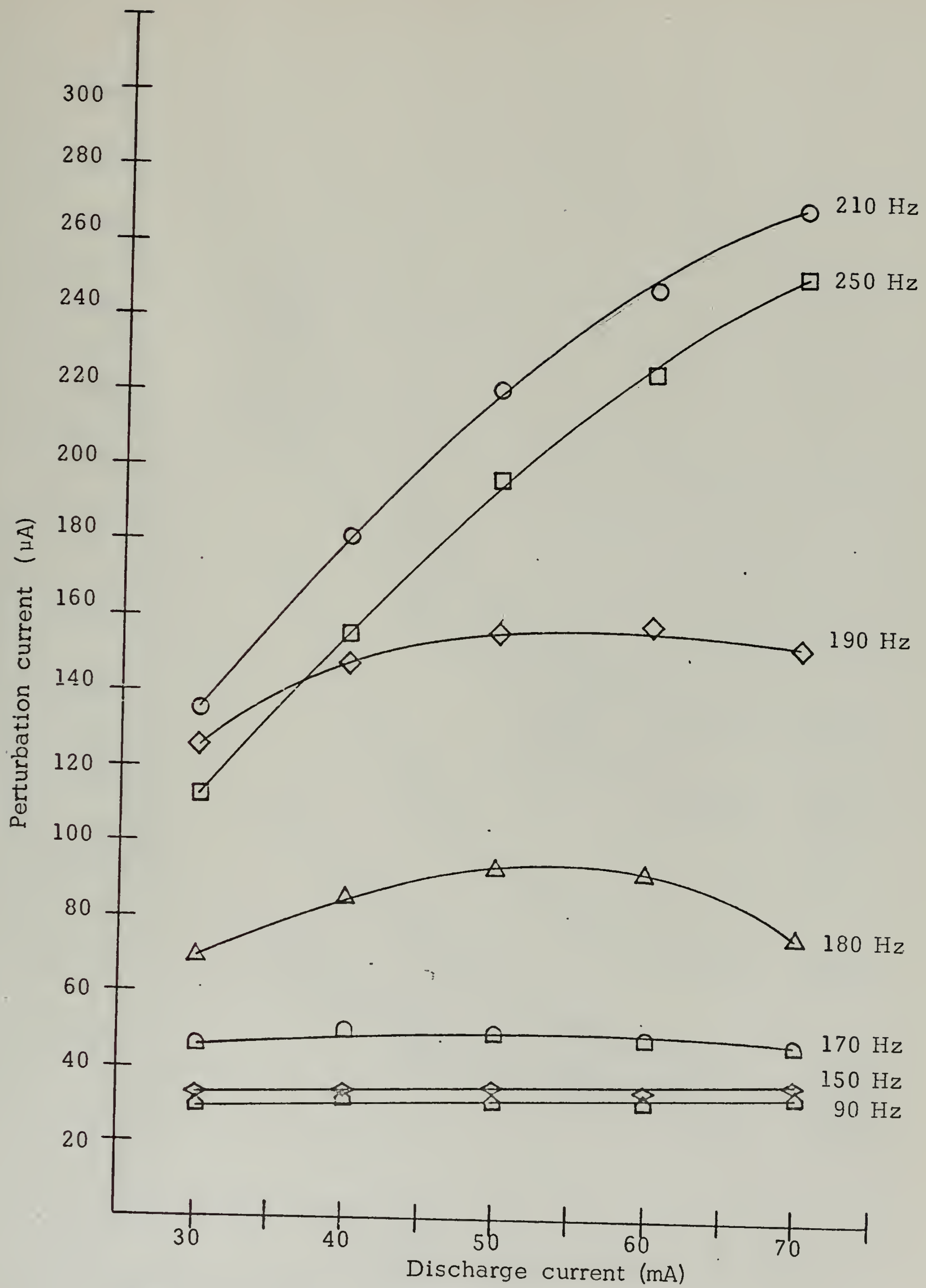

Figure 21. Perturbation current vs. discharge current
$P = 5$ torr, $\tilde{P} = .004$ torr

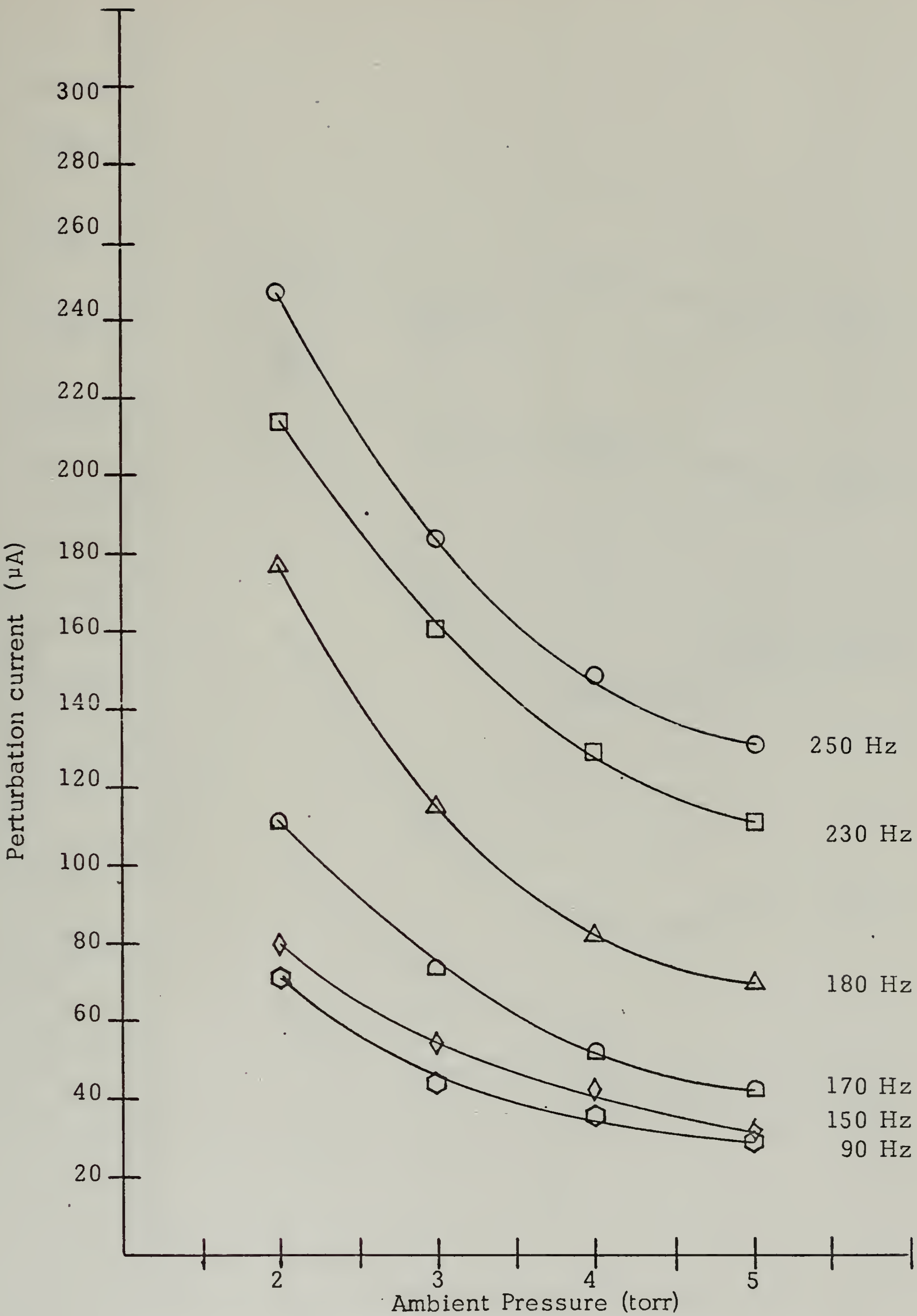

Figure 22. Perturbation current vs. ambient pressure
I_{dc} = 30 mA, $\tilde{P}$ = .004 torr

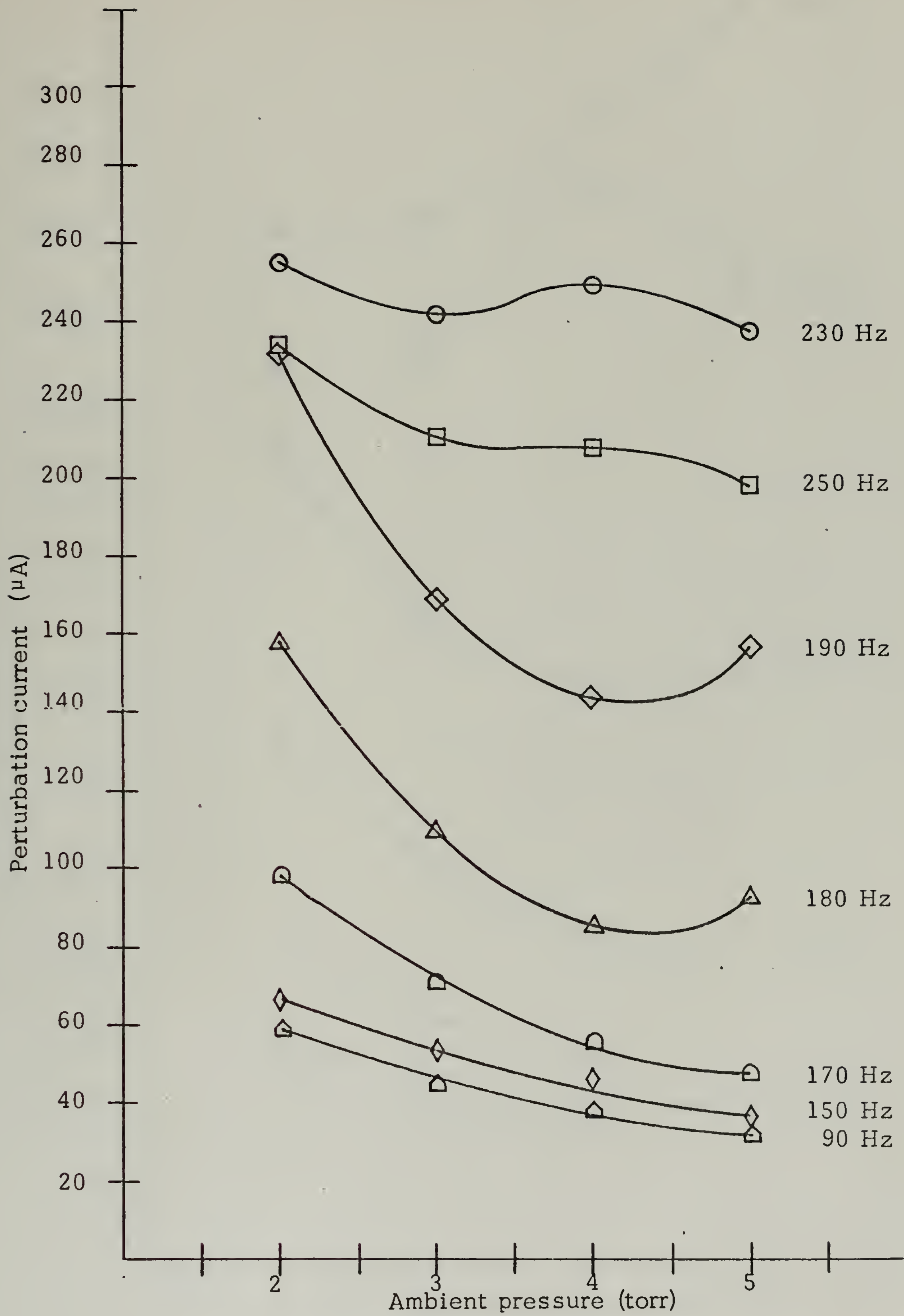

Figure 23. Perturbation current vs. ambient pressure
$I_{dc} = 50$ mA, $\tilde{P} = .004$ torr

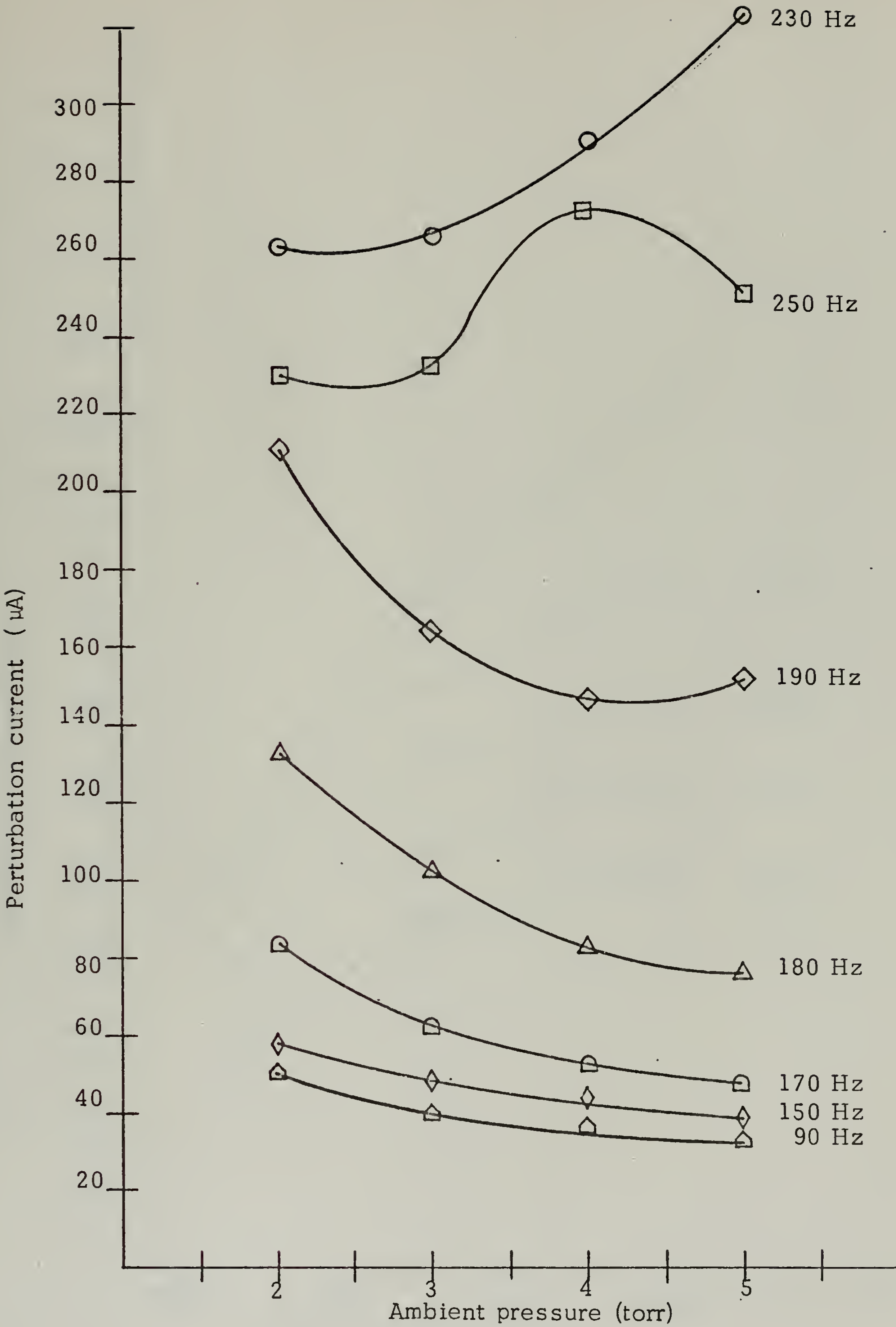

Figure 24. Perturbation current vs. ambient pressure
$I_{dc} = 70$ mA, $\tilde{P} = .004$ torr

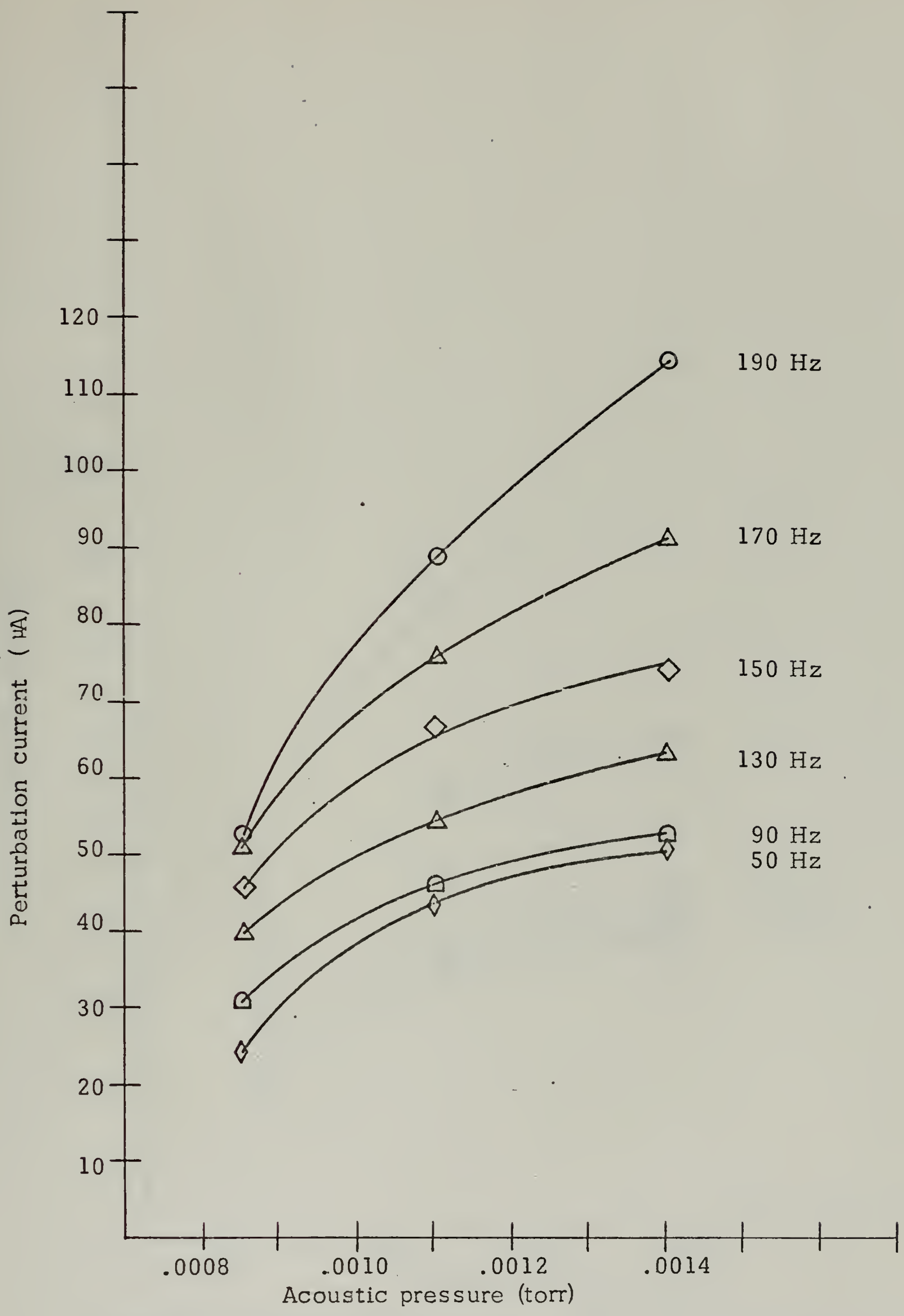

Figure 25. Perturbation current vs. acoustic pressure, I_{dc}=30mA, P = 1 torr

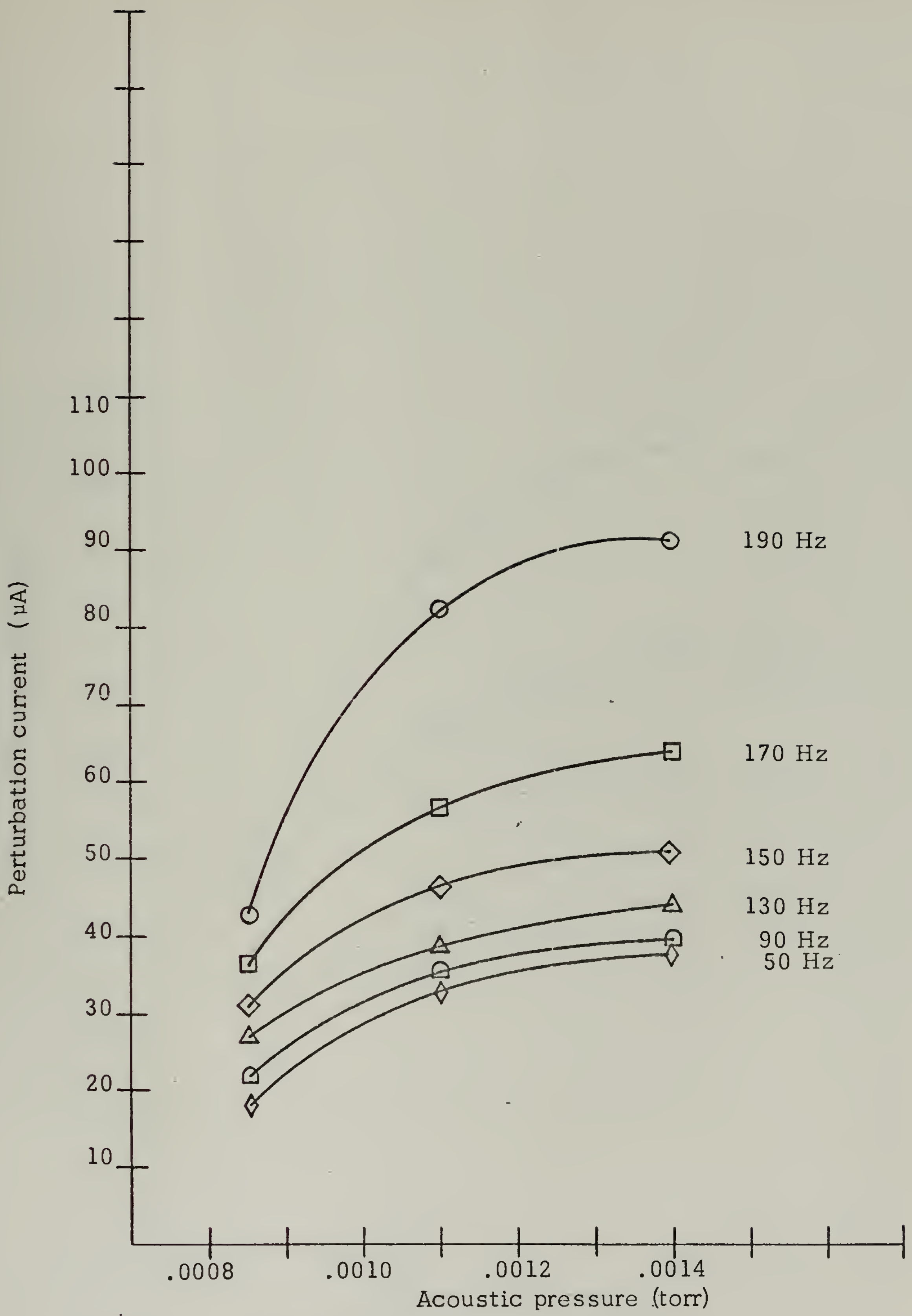

Figure 26. Perturbation current vs. acoustic pressure, I_{dc}=50mA, P = 1 torr

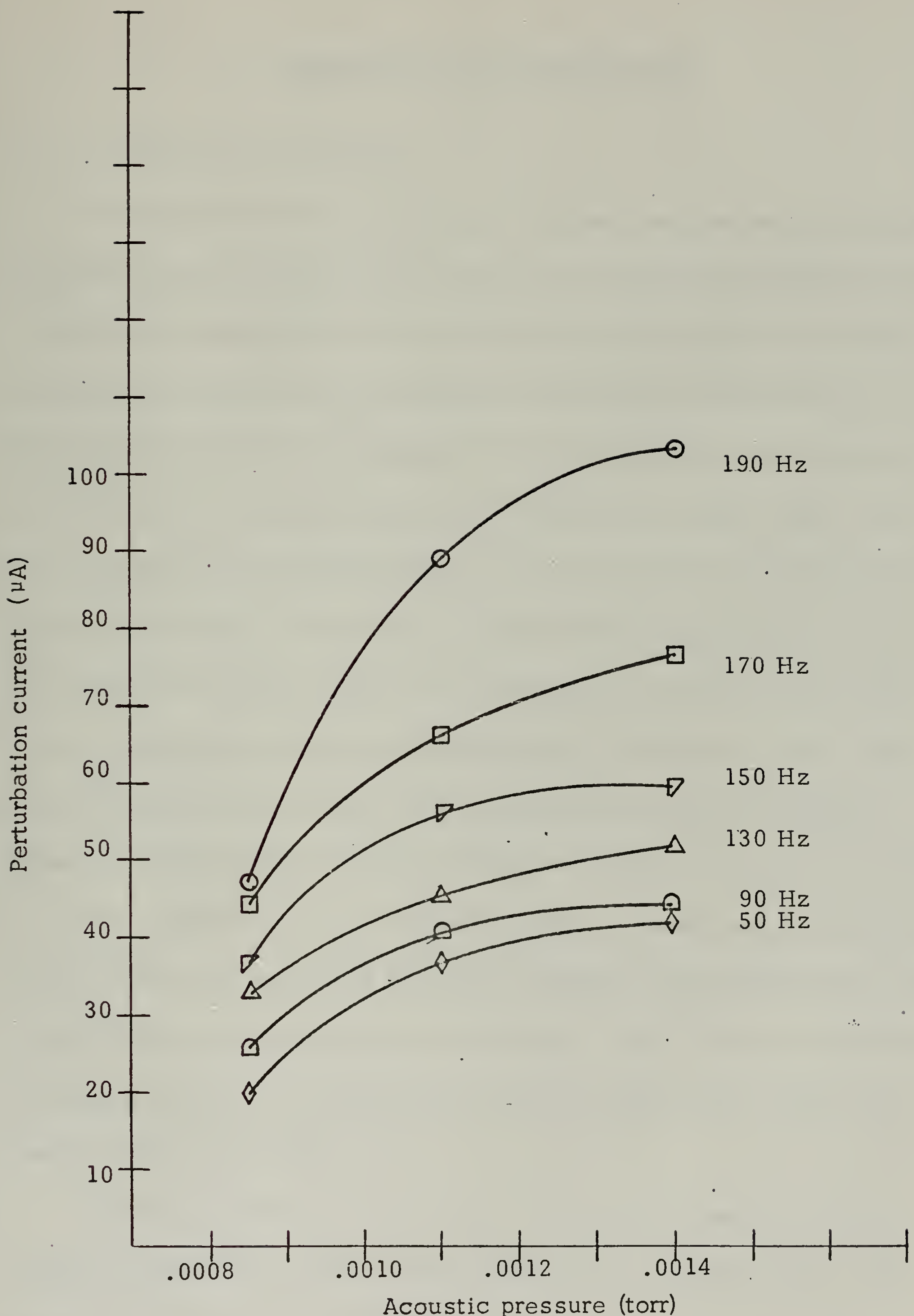

Figure 27. Perturbation current vs. acoustic pressure, $I_{dc} = 70$ mA, $P = 1$ torr

V. DISCUSSION OF THE EXPERIMENT

A. DISCUSSION OF RESULTS

The magnitude of the perturbation current remained nearly constant for frequencies less than 150 Hz with all other parameters held constant. Frequencies greater than 150 Hz produced large changes in the perturbation current with a maximum occurring between 210 Hz and 230 Hz. As the ambient pressure was increased, the perturbation current decreased and in the lower frequency range this decrease was nearly linear. The dc discharge current had little effect on the perturbation current for frequencies less than 170 Hz and an ambient pressure greater than 2 torr. For frequencies greater than 170 Hz and ambient pressures greater than 2 torr, the perturbation current increased with discharge current. For ambient pressures of 1 and 2 torr, the perturbation current showed a general decrease with increased discharge current. These results under the higher ambient pressure conditions might be understood by realizing that the degree of ionization decreased markedly with increased pressure. With fewer ionized particles in the discharge, there was less separation of charged particles. However this does not explain what occurred at lower ambient pressures.

Ingard and Schulz [7] had predicted a critical frequency below which there would be no phase shift between the charged particles and thus no perturbation current would be produced. This critical frequency was given by:

$$\omega_c = \Omega_n \left(\frac{T_n N_n}{T_e N_i}\right) \gamma_n$$

where: $$\Omega_n = (\nu_{ni} + \nu_{ne})$$

The term ν_{jk} is the collision frequency of a particle of the jth type moving through the fluid component k with N_k particles per unit volume. Under the conditions of the nitrogen glow discharge of this experiment, the plasma parameters were T_n ~500°K, T_e ~ 13000°K, N_n ~10^{16}, $N_i = N_e$ ~ 10^{10}, and γ ~1.4. Conservation of momentum requires that the momentum transferred from the ions to the neutrals must be the negative of the momentum transferred from the neutrals to the ions, therefore:

$$\nu_{ni} N_n m_n = \nu_{in} N_i m_i$$

The collision frequency for momentum transfer of ions with neutrals, ν_{ni}, is approximately 10^5 sec^{-1} and m_i ~ m_n so that:

$$\nu_{ni} = \frac{N_i \nu_{in}}{N_n}$$

or $$\nu_{ni} \sim 10^{-1}\ \text{sec}^{-1}$$

Similarly, the momentum transfer between electrons and neutrals can be written:

$$\nu_{ne} N_n m_n (v_n - v_e) = -\nu_{en} N_e m_e (v_e - v_n)$$

but $$v_e >> v_n$$

so that

$$\nu_{ne} = \nu_{en} \frac{m_e N_e}{m_n N_n}$$

where $\nu_{en} \sim 10^5 \ \text{sec}^{-1}$, $\frac{N_e}{N_n} \sim 10^{-6}$, and $\frac{m_e}{m_n} \sim \frac{9.1 \times 10^{-28}}{4 \times 10^{-23}} \sim 2 \times 10^{-5}$.

Therefore:

$$\nu_{ne} \sim (10^5)(10^{-6})(2 \times 10^{-5}) \sim 2 \times 10^{-6} \ \text{sec}^{-1}$$

Now

$$\Omega_n \sim 10^{-1} + (2 \times 10^{-6})$$

$$\Omega_n \sim 10^{-1}$$

The critical frequency predicted by Ingard and Schulz is therefore:

$$\omega_c \sim (10^{-1})(4 \times 10^{-2})(10^6)(1.4)$$

$$\omega_c \sim 5 \times 10^3 \ \text{rad/sec}$$

or

$$f_c \sim 1000 \ \text{Hz}$$

The range of acoustic frequencies used in this experiment were well below this critical frequency, but a perturbation current was measured for all frequencies in this range. Therefore the experimental results were in disagreement with Ingard and Schulz.

The magnitude of the perturbation current as measured by Subertova ranged from 1 to 10 μA whereas the range of perturbation current in this experiment was from 15 to 300 μA. However direct comparison of these

data cannot be made since the acoustic pressure which produced the perturbation current was not measured in the previous experimental work. However, it is known that the speaker used in Subertova's work was considerably smaller than the 10 watt speaker used in this experiment, so that it might be assumed that the magnitude of the acoustic pressure produced by the 10 watt speaker was much greater. Also Subertova operated in a frequency range of 200 Hz to 600 Hz which was above that of this experiment. In addition, the sizes of the discharge tubes were different so that minor differences in plasma parameters might be expected.

There was general agreement between the data of Subertova's work and this project when the experimental parameters were sufficiently close to make a comparison. For instance, both sets of data indicated that the perturbation current was inversely proportional to dc discharge current when the ambient gas pressure was approximately 2 torr.

B. SOURCES OF ERROR

The results obtained in this experiment depended on the calibration of the diode, the speaker, and the Rogowsky Ring. The diode was extremely noisy which made its calibration quite difficult, and any error introduced here would have been compounded further when the speaker was calibrated. Speaker calibration was made more difficult not only because of the noise of the diode but also because of an apparent change of standing wave conditions with speaker gain for frequencies between

50 and 70 cycles. At these low frequencies the acoustic pressure waves as detected by the diode were not strictly sinusoidal but rather appeared to be the superposition of two pressure waves. As the speaker gain was increased, one of the pressure waves became dominant and the waveform changed. It might be pointed out that this was not due to 60 cycle noise as the amplitudes of these waveforms were much greater than the existing 60 cycle noise level. The tendency for the speaker characteristics to change under vacuum and the outgassing of its components with time were another possible source of error.

C. RECOMMENDATIONS FOR IMPROVEMENT

The electrodynamic speaker was the weakest part of this experiment. Besides the difficulties associated with this device which have already been mentioned, a great deal of difficulty was experienced due to speaker failure; approximately ten speakers were destroyed. This destruction came about because of insufficient damping of the speaker cone, particularly at resonance, which caused the small wires leading from the cone of the speaker to the coil to break. When this occurred it was necessary to open the vacuum system to replace the speaker thus exposing the discharge tube to the atmosphere. It then took 3 to 4 days of pumping in order to outgas the speaker. In any future work done in this field, the possibility of another type device to produce a pressure wave should be investigated.

Another possible diagnostic for this experiment is a floating double Langmuir probe which would allow measurement of the electric field strength, which causes the perturbation current, between two points. By determining the conductivity of the plasma, one might be able to calculate the perturbation current.

Further investigation in this field might include a correlation between experimental observation and theory as presented by Ingard and Schulz. Future experimental observations might include measuring the perturbation current in other gases, at higher and lower acoustic frequencies and pressures, and at different locations within the discharge tube.

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13. ABSTRACT

An alternating current produced by an acoustic wave in the positive column region of a glow discharge in nitrogen gas under dc conditions was measured using a magnetic probe in the form of a Rogowsky Ring. The electrodynamic speaker which generated the acoustic wave was calibrated in nitrogen gas in terms of acoustic pressure for frequencies from 50 Hz to 250 Hz at ambient pressures corresponding to glow discharge pressures through the use of a specially constructed mobility-limited thermionic diode. The frequency of the perturbation current was found to be the same as the frequency of the acoustic wave and its magnitude was a function of ambient pressure, dc discharge current, acoustic pressure, and acoustic frequency.

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